HERBICIDAL BEHAVIOR OF THIOBENCARB IN SELECTED FLORIDA SOILS

BY

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Major Department: Horticultural Science

Laboratory, greenhouse, and field studies were conducted to characterize the herbicidal behavior of thiobencarb [S-[(4-chlorophenyl)methyl]diethylcarbamothioate]. Thiobencarb adsorption (K_f) on the soils studied was correlated with soil organic carbon content (r = 0.97) and was in the order Pahokee muck (339 $ml \cdot g^{-1}$) > Everglades muck (169 $ml \cdot g^{-1}$) > Immokalee sand (14 $ml \cdot g^{-1}$). In desorption studies <5% of thiobencarb was removed per desorption step from the two muck soils and was hysteretic. On all soils >93% of thiobencarb remained in the upper 1 cm after leaching during unsaturated flow. During saturated flow the retardation factor (R_T) of thiobencarb on the Immokalee sand was 68, 20, 2, and 1 with 0, 25, 50, and 75%

by volume methanol in 0.01 N $CaCl_2$, respectively. The half-life of thiobencarb averaged 16, 18, and 24 days on Pahokee muck, Everglades muck, and Immokalee sand, respectively, and was longer with 100 kPa soil-water tension and incubated at 25°C than with soil-water tension at 10 kPa and incubated at 35°C.

In greenhouse studies lettuce [Lactuca sativa L.] and weed population reductions occurred primarily between 7 and 14 days after application of thiobencarb. Butterhead and crisphead lettuce stands were lower at 100 than 10 kPa soil-water tension with 4 $kg \cdot ha^{-1}$, but were equally lower with 8 $kg \cdot ha^{-1}$ thiobencarb. Activated charcoal applied at 1.4 $g \cdot m^{-1}$ on the seed enabled lettuce to attain a similar dry weight with 0 or 8 $kg \cdot ha^{-1}$ thiobencarb, but naphthalic anhydride did not protect lettuce from injury. With 8 $kg \cdot ha^{-1}$ thiobencarb on the Immokalee sand, lettuce vigor, and dry weight were reduced more with overhead than subsurface irrigation. Lettuce vigor decreased and weed control increased linearly on the muck soils and quadratically on the sand as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. Lettuce vigor increased sharply and weed control decreased slightly with a preplant incorporated application rather than a preemergence application of 8 $kg \cdot ha^{-1}$ thiobencarb on the muck soils but were not affected by application method on the sand.

In field studies on muck soils, butterhead and crisphead lettuce yields were greater with 8 $kg \cdot ha^{-1}$ thiobencarb applied preplant incorporated than preemergence in the fall but were similar in the spring. Overhead irrigation at 1.25 $cm \cdot da^{-1}$ for 0, 4, or 8 days after seeding did not affect weed control or lettuce yield. Thiobencarb provided moderate to poor early season weed control but reduced hoeing time. Thiobencarb applications without hand hoeing resulted in lettuce yields similar to those with the unhoed checks.

CHAPTER I
INTRODUCTION

Losses due to weeds in the Florida vegetable industry have been estimated to be over $15 million dollars per year (Dusky, 1982). Herbicides are available for weed control in lettuce grown on mineral soils, but presently, none are recommended for preemergence weed control in lettuce grown on muck soils in Florida (Stall, 1987). This lack of effective preemergence herbicides has limited weed control recommendations to the use of paraquat post-directed or glyphosate for stale seed bed preparation. Paraquat is a contact herbicide and glyphosate is a translocated herbicide that kills emerged weeds, but provide no residual control. Hand weeding is used extensively but it is expensive, and not always available.

The acreage of lettuce in Florida has increased from 2800 ha in 1971 to 6500 ha in 1986, with a farm value of $45 million (Fla. Agr. Stat., 1986). About 85% of the lettuce is grown on the high organic matter or muck soils around Lake Okeechobee and most of the other lettuce is grown on the muck soils near Zellwood, Florida, around Lake Apopka. Considering the expansion of lettuce production on muck soils, the need to develop an effective preemergence weed control program in lettuce on these soils has become

increasingly important. Thiobencarb has shown some promise for weed control efficacy in lettuce but in previous studies, weed control and lettuce tolerance have been erratic. The variability in thiobencarb activity has been attributed to differences in rainfall, weed species, and temperature (Dusky, personal communication 1985).

Concern about groundwater contamination from pesticide usage has increased the need for knowledge about the behavior of agricultural chemicals in the environment. Information about the interaction of a pesticide with the soil can also be used to alter management practices to maximize its effectiveness and to minimize adverse effects on the environment.

The objectives of this study were 1) to determine the relationship between soil physical and chemical characteristics and thiobencarb behavior, and 2) to evaluate the effect of management practices on the weed control efficacy of thiobencarb.

Several studies were initiated and results arranged in chapters as follows:

Chapter II. Adsorption, mobility and degradation of thiobencarb as related to soil properties were evaluated in laboratory studies.

Chapter III. Greenhouse and field studies on soil series, irrigation practices and application methods effects on weed control and lettuce tolerance to thiobencarb.

CHAPTER II
BEHAVIOR OF THIOBENCARB IN SOIL

Literature Review

History and Properties of Thiobencarb

Thiobencarb [S-[(4-chlorophenyl)methyl]diethylcarbamothioate] was synthesized and developed by the Kumiai Chemical Industry Company Limited of Japan in 1965. The previous common name was benthiocarb. In 1970, it was marketed under the trade name Saturn for weed control in rice. Chevron Chemical Company purchased thiobencarb marketing rights in the U.S. in 1973 and established the trade name Bolero (Rich, 1981). Thiobencarb is an oily liquid with a pale amber to light yellow color. It is low in water solubility (27.5 ppm at 20°C) but is soluble in xylene, alcohols and acetone. The vapor pressure is $2.2 \cdot 10^{-5}$ mm Hg at 23°C and therefore is not considered volatile (Kumiai, 1977).

Behavior of Thiobencarb in Soil

Soil type has been shown to influence the behavior of herbicides. Clay and organic matter content are the primary factors in predicting herbicide adsorption (Talbert and Fletchall, 1965; Weber and Peter, 1982).

While Chevron Chemical Company has performed adsorption and leaching experiments (Kumiai, 1977), no thorough scientific articles on the subject were found. The activity of thiobencarb is not entirely free from the influence of soil type; however, the extent of such influence was comparatively less than with other soil applied herbicides (Rich, 1981). Thiobencarb was rapidly adsorbed by soil colloids and was classified as having little mobility (Ishikawa et al., 1976). In leaching studies, 74% of thiobencarb was found in the top 1 cm of a clay loam soil (Kumiai, 1977).

The mobility of a herbicide in the soil profile can influence its efficacy as a weed control compound and the potential for ground water contamination. Soil properties (Bailey et al., 1968; Helling, 1971; Lambert et al., 1965) and chemical structure of herbicides (Lambert, 1967; Leopold et al., 1960) also have been shown to influence mobility by affecting the degree of adsorption.

Influence of Environmental Factors on Thiobencarb Activity

The importance of rainfall, irrigation, and soil moisture in promoting herbicide activity has been noted (Ennis, 1954; Stickler et al., 1969). Rainfall can cause activation and leaching of a herbicide (Upchurch and Pierce, 1957). Green and Obien (1969) emphasized the dependence of herbicide concentration in the soil solution

as a function of water content and the partition coefficient:

$$C_w = Q/[m(W_e + K)] \text{ when } W_e > 0$$

where C_w = herbicide concentration in soil solution in μg/g

Q = total herbicide applied in μg

m = total soil weight in g

C_a = herbicide adsorbed by soil in μg/g

K = C_a/C_w = partition coefficient

W_e = gravimetric water content.

They concluded that an increased herbicide concentration in solution does not mean that a herbicide will be more toxic under dry conditions. Lavy (1968) found that herbicide transport to the sorbing surface of the plant root or hypocotyl took place by mass flow or molecular diffusion. The primary effect of soil-water content on herbicide phytotoxicity was associated with herbicide transport in soil water and consequential uptake, not on its soil-water concentration (Geissbühler et al., 1963). The overall effect of soil moisture on pesticide activity was greatest in low organic matter soils and pesticide adsorption had to be weak enough so that water could successfully compete for adsorption sites on soil surfaces (Harris, 1966). Upchurch et al. (1966) found the influence

of rainfall on herbicide activity to vary among herbicides and crop species. Rain did not affect the toxicity of CDAA (2-chloro-N-N-di-2-propenylacetamide) to soybeans and had little effect on cotton. Rain had a significant effect on the toxicity of chloropropham (1-methylethyl 3-chlorophenylcarbamate) and simazine (6-chloro-N,N′-diethyl-1,3,5-triazine-2,4-diamine) to soybeans and cotton. Physical incorporation reduced the need for rainfall or overhead irrigation to activate herbicides by moving them into a position to have phytotoxic action (Upchurch, 1966). An immobile herbicide applied to a dry soil surface was found likely to fail without rain or overhead irrigation (Ennis, 1954; Splittstosser and Derscheid, 1962). The dilution effect must also be considered so that the quantity of herbicide per unit of soil is enough to produce the desired herbicidal effect (Ashton and Dunster, 1961).

The effects of water on thiobencarb activity in rice have been investigated. A delay in flooding rice did not affect the activity of a preemergence application of thiobencarb while butachlor [N-(butoxymethyl)-2-chloro-N-2,6-diethylphenyl)acetamide] and oxadiazon [3-(2,4-dichloro-5-(1-methylethoxy)phenyl)-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one] activity were reduced (Richard and Street, 1984). Thiobencarb injury to rice has been shown to increase with high amounts of rainfall

(Rao et al., 1976) and low amounts of water percolation (Ichizen, 1976).

The control of barnyardgrass by thiobencarb decreases with decreasing soil moisture (Kumiai, 1977). Although increasing soil moisture may increase thiobencarb activity, high soil moisture also favors the germination of purslane (Portulaca oleracea L.) (Yamamoto and Ohba, 1977). Janiya and Moody (1984) showed that the growth of horse purslane (Trianthema portulacastrum L.) was favored by irrigation so the increase in soil moisture may increase herbicidal activity as well as weed growth. Both species of purslane are important weeds on muck soils in Florida (Scudder, 1970).

Temperature may also influence the phytotoxicity of herbicides. Mulder and Nalewaja (1978) found that EPTC (S-ethyl dipropylcarbamothioate), atrazine [6-chloro-N-ethyl-N´-(1-methylethyl)-1,3,5-triazine-2,4-diamine], and alachlor [2-chloro-N-(2,6-diethylphenyl)-N-(methoxy-methyl)acetamide] activity increased with temperature. Trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoro-methyl)benzamide], BAY-5653 [N-(2-benzothiazolyl)-N-methylurea], and chloramben (3-amino-2,5-dichlorobenzoic acid) were not affected by temperature.

McGlamery and Slife (1966) found that adsorption could be reversed with increased temperature for s-triazine herbicides. In general, as temperatures increased,

pesticide adsorbed by soil was less (Leenheer and Ahlrichs, 1971; Mills and Biggar, 1969) but the rate at which equilibrium occurred was quicker. Studies with thiobencarb have shown greater herbicidal activity at high temperatures (Ichizen, 1976; Rich, 1981), but longer residual herbicidal activity at low temperatures (Rich, 1981), while Ishii (1974) found no difference in activity from 12° to 36°C.

The persistence of a herbicide also influences the degree and duration of weed control (Audus, 1964). Persistance was influenced by soil physical and chemical properties (Dao et al., 1979; McGahen and Tiedje, 1980; Zimdahl and Clark, 1982). Thiobencarb was found to maintain its activity in soil for 4 to 5 weeks (Kumiai, 1977). Its half-life was 12 days in a volcanic ash clay, 16 to 64 days in an alluvial clay loam, more than 64 days in a clay loam paddy soil, and 20 days in an upland soybean field soil (Kumiai, 1977). Another report (Weed Sci. Soc. Amer. Handbook, 1979) lists the half-life as 3 weeks under aerobic conditions and 6 to 8 months under anaerobic conditions. Duah-Yentumi and Kuwatsuka (1980) found that under aerobic conditions, the addition of a NPK fertilizer or rice straw increased the degradation rate of thiobencarb. Under anaerobic conditions these amendments had no effect and degradation was slower. Nitrogen appeared to shorten the lag period of thiobencarb degrading microorganisms (Duah-Yentumi and Kuwatsuka, 1982).

Physiological Responses to Thiobencarb

Thiobencarb is a protein synthesis inhibitor (Kumiai, 1977). Kimura et al. (1971) found that thiobencarb inhibited GA induced α-amylase synthesis in rice and barnyardgrass. Ishii (1974) found the concentration of thiobencarb required to cause 50% inhibition of α-amylase synthesis was $5 \cdot 10^{-5}$ M in barnyardgrass (a thiobencarb sensitive species) and $7 \cdot 10^{-4}$ M in rice (a thiobencarb tolerant species), indicating the involvement of protein synthesis.

Thiobencarb was found not to affect seed germination (Al-Mamun and Shimizu, 1979; Ichizen, 1980) but did affect leaf growth. Thiobencarb retarded the extension of new leaves and caused swelling of cells which were often vacuolated (Shibayama and Worley, 1976).

Thiobencarb was found to be rapidly adsorbed by the roots of rice and translocated throughout the plant. After 4 days, only 10% of the parent compound was found in the roots (Eastin, 1975). The amount of thiobencarb found in the roots of barnyard millet (*Echinochloa utilis* Ohwi et Yabuno) was greater than in rice (Nakamura et al., 1977). The absorption and translocation of thiobencarb in its active form were in the order of mesocotyl > coleoptile > root > first leaf (Kumiai, 1977) for both barnyardgrass and rice. Nakamura et al. (1974) found that translocation rate of thiobencarb among plant species was in the order, wild

amaranth (*Amaranthus blitum* L.) = smartweed (*Polygonum nodesum* Pers.) > common lambsquarters (*Chenopodium album* L.). The translocation from the root to the leaf or to other plant parts among the broadleaf weeds wild amaranth, smartweed and lambsquarters (thiobencarb tolerant) was less extensive than in the gramineaceous weed barnyardgrass (thiobencarb susceptible).

Materials and Methods

Adsorption-Desorption Studies

The adsorption of thiobencarb on surface samples from three soil series (Table 2.1) was determined by a soil slurry batch technique (Talbert and Fletchall, 1965). One-gram subsamples of air-dried soil sieved through a 2-mm mesh screen were weighed into 20-ml screw top centrifuge tubes. Solutions containing approximately 11,000 $dpm \cdot ml^{-1}$ ^{14}C thiobencarb (uniformly ring labelled, sp. act. 4 millicuries per millimole ($mCi \cdot mmole^{-1}$) were mixed with additional nonlabelled thiobencarb so that concentrations of 0, 1.98, 3.85, 5.53, 7.34, and 8.85 $\mu g \cdot ml^{-1}$ thiobencarb in 0.01 N $CaCl_2$ were obtained. Thiobencarb solution concentrations were determined by high performance liquid chromatography (HPLC). The HPLC system consisted of a UV detector set at λ = 254 nm, 25 cm C-18 cartridge column, 3 cm guard, and a 75/25 methanol/water mobile phase at a

Table 2.1. Properties of the soils.

Series	Taxonomic classification	Source	Organic carbon[z]	30 kPa moisture[y]	pH[x]
			---- %	---	
Pahokee muck	Euic hyperthermic Lithic Medisaprists	Belle Glade	48.6	130	6.6
Everglades mucky peat	Euic hyperthermic Typic Medihemists	Zellwood	34.1	82	7.2
Immokalee fine sand	Sandy siliceous hyperthermic Arenic Haploquods	Zellwood	1.1	9	5.7

[z]Determined by dry combustion (Nelson and Sommers, 1982) where organic carbon × 1.72 = organic matter.
[y]Percent by weight water on a dry weight basis at 30 kPa soil-water tension.
[x]2:1 soil:water paste.

flow rate of 1.75 $ml \cdot min^{-1}$. The retention time was 4.75 min. Ten milliliters of the thiobencarb solution were pipetted into the centrifuge tubes. They were capped and placed on a horizontal shaker at 185 rpm for a 24-hr equilibrium period. After being shaken, the tubes were centrifuged at 1500 rpm for 20 min, and 1 ml of the supernatant was placed in a scintillation vial with 10 ml of Scintiverse II (Fisher Scientific) cocktail. The activity present in the samples was determined by liquid scintillation.

The quantity of herbicide adsorbed was determined by calculating the difference between the initial herbicide concentration ($dpm \cdot ml^{-1}$) and the concentration present in the equilibrium solution after the herbicide was adsorbed onto the soil. All treatments were replicated four times. Adsorption values (K_f and K_{oc}) were determined and the isotherms treatment means were separated by their 95% confidence intervals.

Three successive desorptions were performed to determine the retention characteristics of thiobencarb on these three soil series. Desorption isotherms were conducted by removing 7 ml of supernatant (1 ml was previously removed in the adsorption study) and replacing it with 8 ml of 0.01 N $CaCl_2$. The tubes were shaken, centrifuged, sampled, counted, and the data were analyzed as previously described.

Mobility Study: Unsaturated Flow

The leaching of thiobencarb in the three soil series during unsaturated flow was investigated using vertical glass columns. The columns were composed of 23 glass rings, 1 cm in depth and 4.4 cm in diameter. The columns were packed with air-dried soil and approximately 0.5 µCi of ^{14}C labeled thiobencarb was applied to the soil surface and allowed to dry. Filter paper (Whatman No. 42), glass microfiber paper, and glass wool were placed on top of the soil column to disperse the water.

The columns were leached with 0.01 N $CaCl_2$ from a Mariotte buret kept at a positive head of 53 cm. The volume of solution applied and the duration of the leaching were recorded until the wetting front descended 20 cm.

The leached column was sectioned into twenty 1-cm segments and subsamples were taken for moisture determination to account for differences in weight and quenching due to water. Three subsamples of each segment were placed in a scintillation vial with 15 ml of scintillation cocktail (Scintiverse II) and shaken for 24 hr. After samples were removed from the shaker they were allowed to settle for 24 hr and assayed for ^{14}C activity as described by Lavy et al. (1972). Means were separated by Duncan's Multiple Range test at the 5% level of significance.

Mobility Study: Saturated Flow

A solid glass column (2.5 cm i.d.) was packed with 4 cm of soil (Immokalee fine sand). Both ends of the column were fitted with teflon filter disks in direct contact with the soil to promote an even distribution of the influent solution and minimize dispersion at the effluent end. The column was saturated with 0.01 N $CaCl_2$ applied with a HPLC pump at a flow rate of 3.0 $ml \cdot min^{-1}$ overnight. The saturation of the column, bulk density and pore water volume were determined by weighing the column before and during the saturation process until a constant weight was obtained. The bulk density (ρ) was 1.67 $g \cdot cm^{-3}$ and volumetric water content (Θ) at saturation was 0.488 $ml \cdot cm^{-3}$. The pulse width, activity, and collection periodicity needed for the tritium and thiobencarb experiments were determined with a BTC4 computer simulation model (Ron Jessup, personal communication, 1988). The instantaneous switch from 0.01 N $CaCl_2$ to tritium or thiobencarb in 0.01 N $CaCl_2$ was performed with a Rheodyne switching valve. Separate tests in the absence of the soil column on the switching valve, teflon, and stainless steel tubing reconfirmed that tritium, thiobencarb, and 0.01 N $CaCl_2$ solutions could be switched without any tailing of the previous influent. Radiopurity of the ^{14}C-thiobencarb was determined by thin layer chromatography. Tritium (a

nonadsorbed conservative tracer) in 0.01 N $CaCl_2$ was pulsed at 3.0 ml·min^{-1} onto the column. The effluent was collected at 20-second intervals with an automatic fraction collector into preweighed scintillation vials. Tritium activity was determined by a Searle Delta 300 liquid scintillation counter in Scintiverse II cocktail. A peclet number was calculated which described the flow characteristics of the column with a nonadsorbed tracer. Data generated from the elution of tritium pulsed through the soil column were used to calculate an elution (breakthrough) curve.

The influent was switched from pure 0.01 N $CaCl_2$ to ^{14}C-labeled thiobencarb (25 ppm, 11,000 dpm·ml^{-1}) in 0.01 N $CaCl_2$ and 480 ml (50 pore volumes) was pulsed through the column at 3 ml·min^{-1}. After 50 pore volumes, the influent was switched back to 0.01 N $CaCl_2$. The effluent was collected in 12-ml fractions until 1920 ml of effluent (220 pore volumes) were collected. A 1-ml aliquot was removed from each 12-ml fraction and the relative effluent concentration [effluent concentration·initial influent concentration^{-1} ($C \cdot C_0^{-1}$)] were determined by liquid scintillation. This experiment was repeated with a freshly packed column. Breakthrough curves were also determined in methanol-water mixtures to compare these solvent systems to totally aqueous systems in predicting thiobencarb retention

in soils. Methanol was used at 0, 25, 50, and 75% by volume of the 0.01 N $CaCl_2$ solutions and the experimental procedure was the same as with purely aqueous systems. All experiments were performed at room temperature (22°C).

The breakthrough curves were fitted to a sorption model to estimate the retardation factor (R_T) at each methanol cosolvent fraction as follows:

$$P = (vL/D);\ D = \alpha v \text{ or } P = (L/\alpha)$$

$$R_T = [1 + \rho K_f/\Theta]$$

where P = dimensionless peclet number

V = pore water velocity ($cm \cdot hr^{-1}$)

L = column length (cm)

D = hydrodynamic dispersion coefficient ($cm^2 \cdot hr^{-1}$)

α = dispersivity (cm)

ρ = soil bulk density ($g \cdot cm^{-3}$)

K_f = Freundlich sorption coefficient

Θ = volumetric water content ($cm^3 \cdot cm^{-3}$).

A curve fitting computer program CFITIM3 (van Genuchten, 1981), based on nonlinear least-squares optimization techniques was used to calculate the peclet and retardation factor values. The retardation values were separated by their 95% confidence intervals.

Degradation Study

All three soils (Table 2.1) were air dried after having been in storage at field moisture 6 months prior to the initiation of this experiment. The water contents at specific soil-water tensions for each soil are listed in Table 2.2. The experimental design was a split-plot with soil temperature as the main plot, and soil series and soil moisture as subplots.

Samples of each soil (100 g oven dry basis) were placed in 1 liter Erlenmyer flasks. Uniformly phenyl ring labeled ^{14}C-thiobencarb with a specific activity of 41.7 $mCi \cdot mmole^{-1}$ was checked by thin layer chromatography and found to have >99% radiopurity. Aqueous solutions of ^{14}C and ^{12}C-thiobencarb were prepared so that a 5 ml aliquot spread on top of the soil provided 0.04 $\mu Ci \cdot g^{-1}$ of ^{14}C-thiobencarb with 12 ppm of ^{12}C-thiobencarb. Additional water was added to bring the soils to either 10 or 100 kPa soil-water tension. Five-gram samples of soil from each flask were removed immediately to determine the initial amount of ^{14}C-thiobencarb. The flasks were stoppered and weighed so that soil-water tensions could be maintained gravimetrically. A 10 ml beaker containing solutions of KOH (2 to 10 M) was suspended just above the soil to trap the evolved $^{14}CO_2$. The flasks were placed in constant temperature chambers at either 25 or 35±2°C. Soil samples were removed at 3, 7, 14, 28, and 42 days after initiating

Table 2.2. Water contents of the soils at 10 and 100 kPa.

Soil series	Soil-water tension (kPa) 10	100
	Water ($ml \cdot 100\ g^{-1}$)	
Pahokee muck	135.5	93.6
Everglades peaty muck	90.2	60.2
Immokalee fine sand	8.4	5.2

incubation. The KOH in the $^{14}CO_2$ traps were sampled and replenished with fresh KOH on the 3rd and 7th day, and once a week thereafter for 42 days.

The ^{14}C-thiobencarb and ^{14}C-degradation products in the soil were extracted by placing 5 g of soil in a 40-ml screw top vial with 20 ml of pesticide grade acetone. The vials were shaken for 2 hr and then vacuum filtered through a Buchner funnel fitted with Whatman No. 42 filter paper. The soil was extracted with an additional 3×20 ml volumes of acetone and the extracts were combined. The extracts were dried over anhydrous sodium sulfate and their volumes were reduced to 2 ml in precalibrated test tubes. One milliliter of this concentrated extract was removed to determine its ^{14}C activity. The ^{14}C activity was determined by liquid scintillation in a cocktail consisting of (all scintillation grade) 6 g of (2,5-Diphenyloxazole) PPO, 0.75 g (1,4-bis[5-Phenyl-2-oxazolyl]-benzene) POPOP, 400 ml 2-methoxyethanol, and 600 ml of toluene. This cocktail formula was used throughout this experiment. Approximately 0.2 ml of the extract was spotted on precoated 0.25 mm, nonfluorescent silica gel G plates (E. Merck, Darmstat, West Germany). Purified ^{14}C thiobencarb and metabolites, which were obtained by extracting degraded thiobencarb from the previous adsorption experiment, were spotted alongside the samples as a reference. The plates

were developed in a chloroform/diisopropyl ether/n-hexane/acetic acid (10/10/10/1) solvent system (Duah-Yentumi and Kuwatsuka, 1980). After the plates were developed and air dried, reference spots of radioactive ink were placed at random near the top of the plate which later assisted in aligning the plate. The plates were placed against Kodak SB-5 x-ray film for approximately 3 weeks in order to detect radioactive areas. The relative concentrations of parent and metabolites of thiobencarb were determined by scraping the radioactive areas and assaying them by liquid scintillation.

The $^{14}CO_2$ in the KOH solutions were determined by liquid scintillation counting (Sissons, 1976). One-half milliliter of the KOH was transferred to a scintillation vial and 15 ml of scintillation cocktail was added. All counts were corrected for background and quenching.

Since not all of the activity was recovered through soil extraction and $^{14}CO_2$ traps, the extracted soil was combusted to determine the amount of bound ^{14}C labeled compounds. A Packard Tri-Carb sample oxidizer was used to combust the soil and the evolved $^{14}CO_2$ was trapped in a scintillation solution containing 6 ml of Carbo-Sorb and 12 ml of Permafluor (Packard Instrument Co.) and quantified by liquid scintillation counting. The extraction and combustion experiments were run in duplicate. The data

were analyzed by ANOVA and treatment means were separated by orthogonal comparison.

Results and Discussion

Adsorption-Desorption Studies

The adsorption of thiobencarb (Table 2.3) on the three soils was significantly correlated (O.C. vs K_f $r = 0.97$) with organic carbon content. The linearity of the isotherm slopes (1/N) ranged from 0.92 to 0.95 in the adsorption and desorption studies. The Pahokee muck, Everglades muck, and Immokalee sand adsorbed 97, 94, and 56% of the ^{14}C-thiobencarb out of solution, respectively. The two muck soils adsorped greater amounts of thiobencarb on a whole soil basis (K_D, K_f, or %), but the Immokalee sand adsorbed greater amounts of thiobencarb per unit of organic carbon (K_{oc}). The greater activity of the organic carbon in the sand may be due its more advanced state of decay and different parent material. As organic matter decomposes the percent of the organic fraction consisting of humic acid increases (Zelazny and Carlisle, 1974) and it has been found that adsorptive capacity among organic materials is greatest with humic acid (Adams, 1973). Furthermore, in soils with high organic carbon contents the organic matter may be more aggregated resulting in a decrease in the available adsorptive surface per unit weight of organic

Table 2.3. Adsorption isotherms of thiobencarb on three soil series.

Soil	O.C.[z] (%)	K_D[y] ($ml \cdot g^{-1}$)	K_f[x] ($ml \cdot g^{-1}$)	$\frac{1}{N}$[w]	K_{oc}[v] ($ml \cdot g^{-1}$)	Ads.[u] (%)
Pahokee muck	48.6	372	339±16	0.94	765	97
Everglades muck	34.1	184	169±12	0.92	539	94
Immokalee sand	1.1	13	14±1	0.95	1195	56

[z]Organic carbon (O.C.) (correlation coefficient between O.C. and K_f is r = 0.97 which is significant at the 5% level).
[y]Sorption coefficient (K_D).
[x]Freundlich sorption coefficients (K_f) and their 95% confidence limits (Y intercept of the regression).
[w]Degree of linearity over the concentration range tested (slope of the regression) (1/N).
[v]K_D sorption constant ÷ % organic carbon (K_{oc}).
[u]Herbicide in the adsorbed state (Ads. %).

carbon (Hamaker et al., 1966) and the variability in K_{oc} values may be due to differences in "efficiency" of soil organic carbon among soils (Lambert, 1968). Adsorption in the muck soils may be totally dependent on its organic carbon.

By using the equation log K_{oc} = 3.64 - 0.55 log pesticide water solubility (Kenaga and Goring, 1980) the K_{oc} is estimated to be 672, which is within the range of values determined in this experiment. These K_{oc} values are important factors in evaluating the potential for groundwater contamination by such computer models as PRZM (Carsel et al., 1984) and LEACH (Laskowski et al., 1982).

The desorption isotherms are presented in Table 2.4. Desorption K_f values were in the order Pahokee muck > Everglades muck > Immokalee sand which were inversely proportional to the percent removed from the soil (desorbed). In the Pahokee muck, the K_f from the first desorption was not significantly different from its adsorption value and was equivalent to 2.8% of that which was previously adsorbed. The second and third desorptions yielded significantly less thiobencarb from the soil than the first desorption but were not significantly different from each other. In the Everglades muck, the first desorption K_f value was significantly greater than the

Table 2.4. Desorption isotherms of thiobencarb from soil with three consecutive desorptions with 8 ml of 0.01 N $CaCl_2$.

Soil	Desorption	K_D[z] ($ml \cdot g^{-1}$)	K_f[y] ($ml \cdot g^{-1}$)	$\frac{1}{N}$[x]	K_{oc}[w] ($ml \cdot g^{-1}$)	Des.[v] (%)
Pahokee muck	First	372	320±10	0.96	694	2.8
	Second	433	427±14	0.99	891	2.1
	Third	451	412±24	0.95	927	2.0
Everglades muck	First	211	206±6	0.98	539	4.5
	Second	252	237±8	0.99	686	3.5
	Third	266	274±12	1.00	846	3.4
Immokalee sand	First	19	19±2	.98	1593	34.6
	Second	22	22±2	1.00	1873	22.7
	Third	22	23±3	1.00	1896	16.6

[z]Sorption coefficient (K_D).
[y]Freundlich sorption coefficients (K_f) and their 95% confidence limits (Y intercept of the regression).
[x]Degree of linearity over the concentration range tested (slope of the regression) (1/N).
[w]K_D sorption constant ÷ % organic carbon (K_{oc}).
[v]Herbicide desorbed from the soil (Des. %).

adsorption K_f and significantly less thiobencarb was removed from the soil with each successive desorption. In the Immokalee sand the first desorption K_f was significantly greater than the adsorption K_f, but none of the desorptions were significantly different from each other. Decreases in the amount of herbicide desorbed from the soil in comparison to that adsorbed, and with successive desorptions are referred to as the hysteresis effect (Rao and Davidson, 1980). The exact causes of this effect are still in dispute but may be due to experimental artifacts.

Mobility Study: Unsaturated Flow

Data on the physical characteristics of the columns used in this study are listed in Table 2.5. The movement of thiobencarb upon leaching the soil columns with 0.01 N $CaCl_2$ to a 20 cm depth was minimal (Table 2.6). In the Pahokee muck 98.7% of the ^{14}C-thiobencarb remained in the top 1 cm and 1.3% was found in the 1 to 2 cm depth. In the Everglades muck 99.2% of the ^{14}C-thiobencarb remained in the top 1 cm soil segment. Thiobencarb was slightly more mobile in the Immokalee sand than the mucks; 94% remained in the top 1 cm of soil, and 5% leached to the 1 to 2 cm depth. The minimal leaching of thiobencarb in this experiment is in agreement with the low amounts of desorbable thiobencarb in the adsorption-desorption study

Table 2.5. Physical data for column leaching (unsaturated flow) studies.

Soil	ρ^z ($g \cdot cm^{-3}$)	I^y (cm)	$V_0{}^x$ ($cm \cdot min^{-1}$)	$\Theta_i{}^w$ ($cm^3 \cdot cm^{-3}$)	$\Theta_f{}^v$ ($cm^3 \cdot cm^{-3}$)	Infiltration time (hr)
Pahokee muck	0.36	13.2	0.04	0.058	0.72	7.92
Everglades muck	0.42	12.1	0.05	0.026	0.63	6.27
Immokalee sand	1.65	4.7	0.13	0.004	0.24	2.43

[z]Packed bulk density (ρ).

[y]Equivalent depth of water added to the column on a surface area basis (I).

[x]Average velocity of the wetting front (V_0).

[w]Initial volumetric water content (Θ_i).

[v]Final volumetric water content (Θ_f).

Table 2.6. Distribution of ^{14}C-thiobencarb in soil with unsaturated flow during leaching.

Column segment (cm)	Soil series		
	Pahokee muck	Everglades muck	Immokalee sand
	Total thiobencarb (%)		
0-1	98.7 a[z]	99.2 a	94.0 a
1-2	1.3 b	0.8 b	5.0 b
2-3	0.0 c	0.0 c	0.6 c
3-7	0.0 c	0.0 c	0.4 c
7-20	0.0 c	0.0 c	0.0 d

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

(Table 2.3). Kumiai (1977) also found that thiobencarb was not very mobile with 73% remaining in the top 1 cm of a clay loam soil leached under ponded conditions. The 1.3% of thiobencarb in the 1 to 2 cm soil segment of the Pahokee muck may be an overestimate due to the expansion of the soil in the column during water infiltration. In addition to the greater adsorptive capacity of the muck soils than the sandy soil, their slower infiltration rates (V_0) would allow for greater re-adsorption of thiobencarb from solution.

Mobility Study: Saturated Flow

The pulse of tritium eluted through the column of Immokalee sand was collected, and the data are presented in Fig. 2.1. Water movement during influx (tritium pulse loading) and efflux (tritium pulse elution) were similar. At 1 pore volume, the relative concentration of tritium was approximately 0.5, indicating that tritium was not retarded ($R_T = 1$) due to adsorption. A peclet number of 128 was determined from the tritium curve which relates to a hydrodynamic dispersion coefficient (α = column length in centimeters·peclet number^{-1}) of 0.03 cm. This low level of hydrodynamic dispersion indicated that deviations from ideal flow due to dead space (immobile soil-water regions) were negligible and the column was packed uniformly.

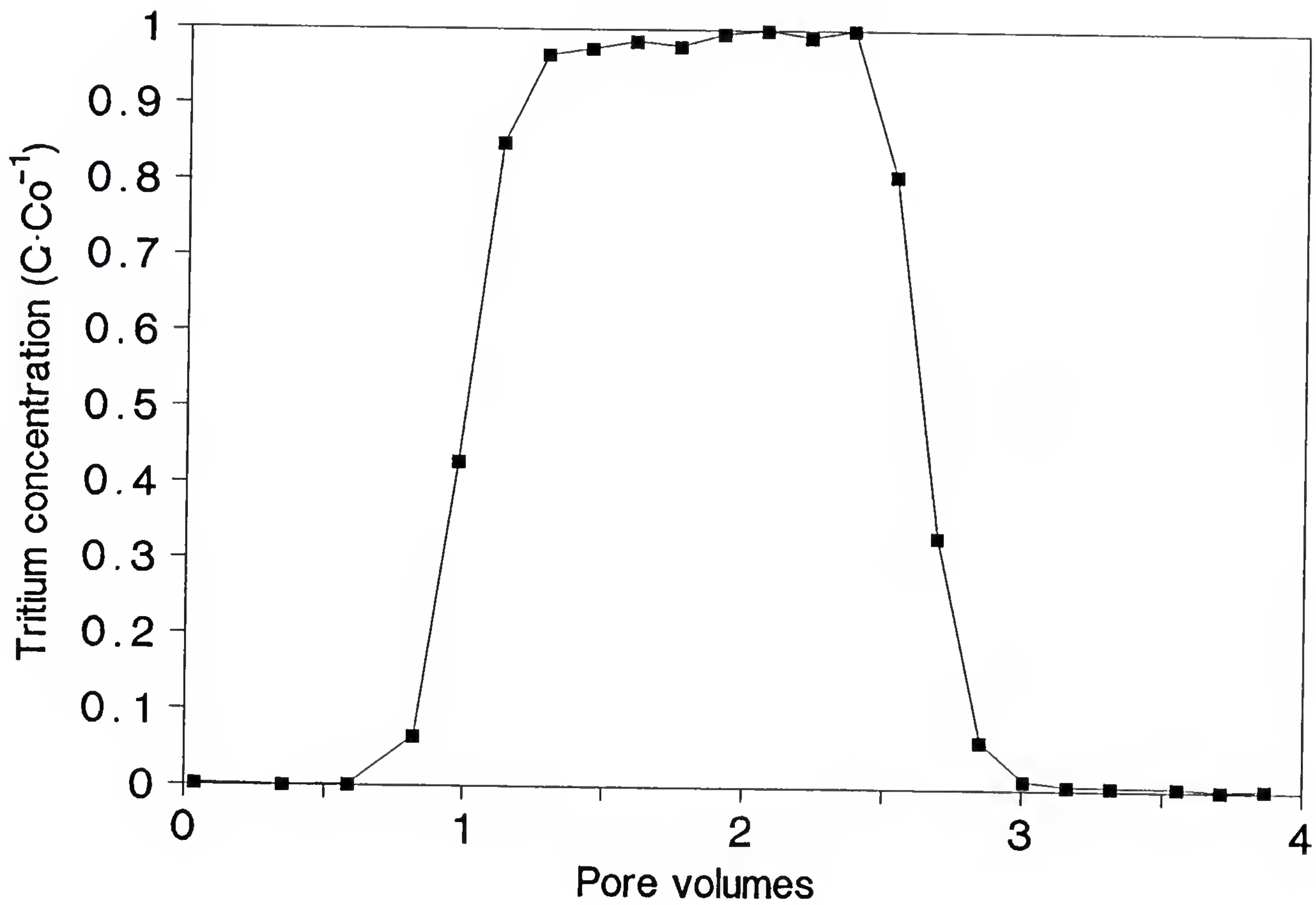

Fig. 2.1. Relative tritium concentration (concentration effluent·initial influent concentration^{-1}) as a function of pore volumes (volume of water contained in saturated soil pores) on an Immokalee sand with a tritium pulse of 1.72 pore volumes in 0.01 N $CaCl_2$.

Data on the mobility of thiobencarb in an Immokalee sand eluted with 0.01 N $CaCl_2$ are shown in Fig. 2.2. There was a gradual increase in the relative concentration of thiobencarb eluted between 0 and 30 pore volumes. This may have been due to an initial rapid sorption to "instantaneous sites" followed by time dependent sorption processes. This phenomenon has been suggested to be diffusion-controlled accessibility to sorption sites (Rao and Jessup, 1983) and seems likely in the absence of immobile soil-water regions as indicated by the tritium breakthrough curve. Also, thiobencarb self-absorption may have occurred early under the nonequilibrium conditions of this experiment. Between 30 and 50 pore volumes of influent, the relative concentration of thiobencarb in the effluent increased rapidly. The influent was changed from ^{14}C-thiobencarb in 0.01 N $CaCl_2$ to 0.01 N $CaCl_2$ at 50 pore volumes influent. At 52 pore volumes influent, the relative thiobencarb concentration abruptly dropped from 0.44 to 0.40 of the initial concentration. It appears that the desorption process was also controlled by a two-site chemical kinetics system and occurred in a series or stepwise fashion in comparison to the adsorption process during site loading. This stepwise event was in agreement with the desorption isotherms which indicated an initial lag in the amount of desorbable thiobencarb compared to the adsorption isotherm. The occurrence of the maximum

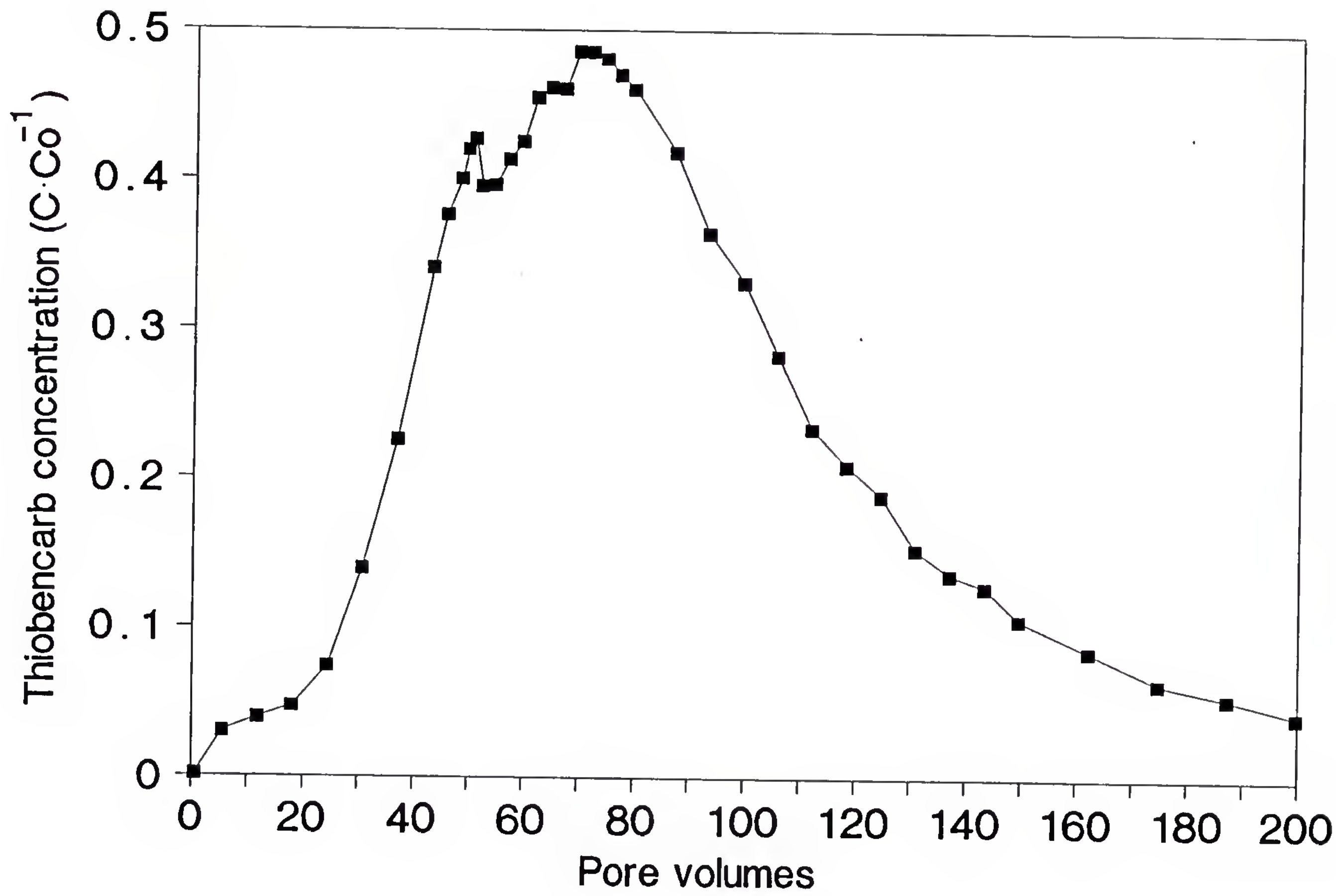

Fig. 2.2. Relative thiobencarb concentration (concentration effluent·initial influent concentration^{-1}) as a function of pore volumes (volume of water contained in saturated soil pores) on an Immokalee sand with a thiobencarb pulse width of 50 pore volumes in 0.01 N $CaCl_2$.

effluent concentration at 70 pore volumes (well after the thiobencarb pulse was discontinued at 50 pore volumes) indicated that the desorbed thiobencarb was eluted from the column slightly behind the front of the thiobencarb-free solution and was eluted as a sharp pulse. The tailing (slow elution of thiobencarb) of the elution front between 120 and 200 pore volumes was also indicative of diffusion-controlled desorption through the soil organic matter matrix.

With an increase in methanol concentration from 0 to 75% by volume in 0.01 N $CaCl_2$ influent solutions, thiobencarb was eluted in fewer pore volumes (Figs. 2.3, 2.4, and 2.5). The retardation factors were 67.9, 20, 1.94, and 1.16 for 0, 25, 50, and 75% by volume methanol, respectively (Table 2.7). The sharp drop and rise in effluent concentration after the ^{14}C-thiobencarb pulse was discontinued with the purely aqueous system did not occur with methanol. The tailing (slow elution of thiobencarb) of the curves after the thiobencarb pulse was discontinued also decreased as methanol concentration increased. With 75% methanol, the retardation factor was 1.2 (Table 2.7) which indicated that thiobencarb behavior was similar to tritium (retardation factor 1.0), a nonadsorbed solute. The greater partitioning of thiobencarb into the desorbed phase with eluting solutions containing methanol can be explained by the concept of surface tension. Thiobencarb

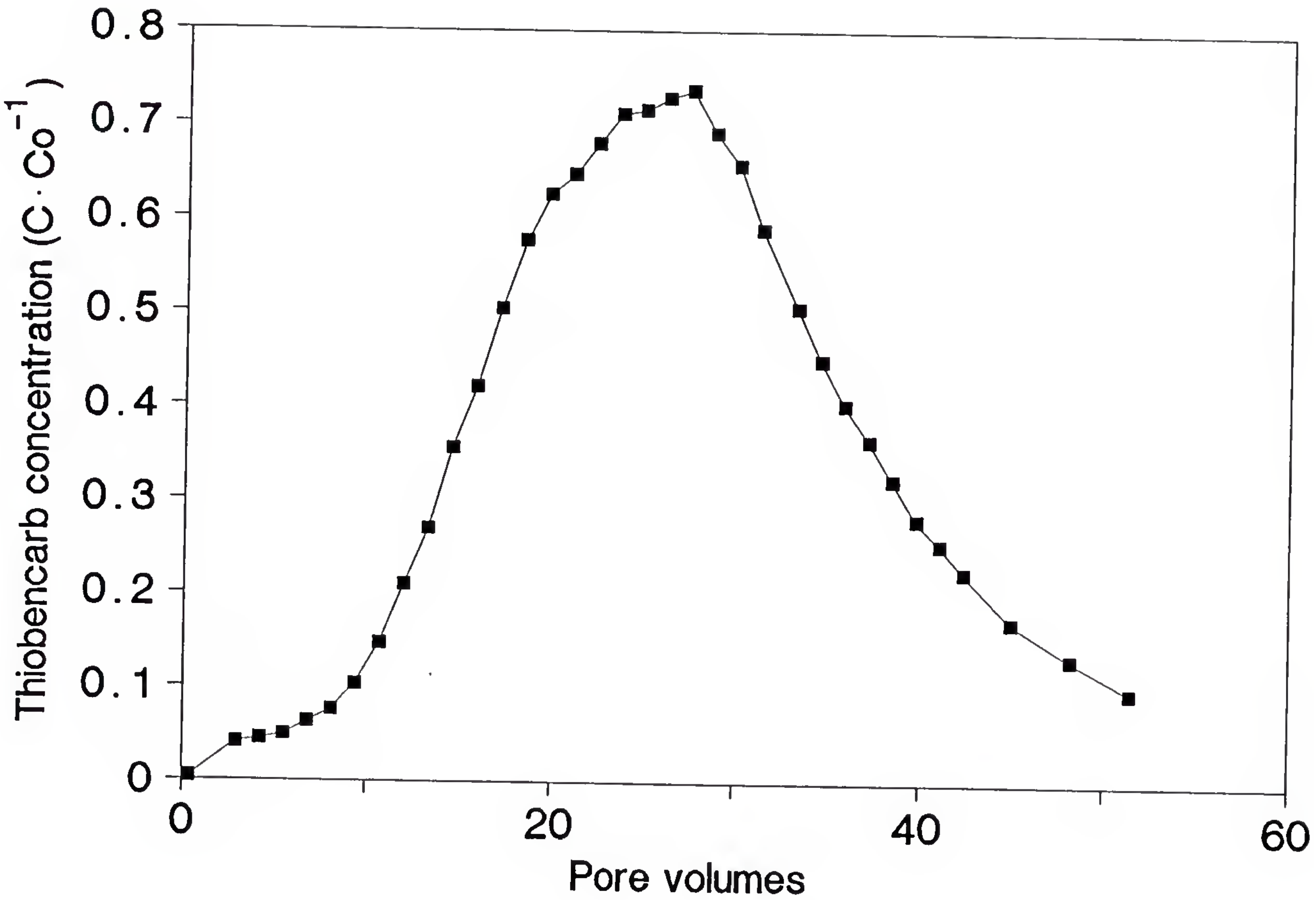

Fig. 2.3. Relative thiobencarb concentration (concentration effluent·initial influent concentration^{-1}) as a function of pore volumes (volume of water contained in saturated soil pores) on an Immokalee sand with a thiobencarb pulse width of 19 pore volumes in 0.01 N $CaCl_2$ with 25 percent by volume methanol.

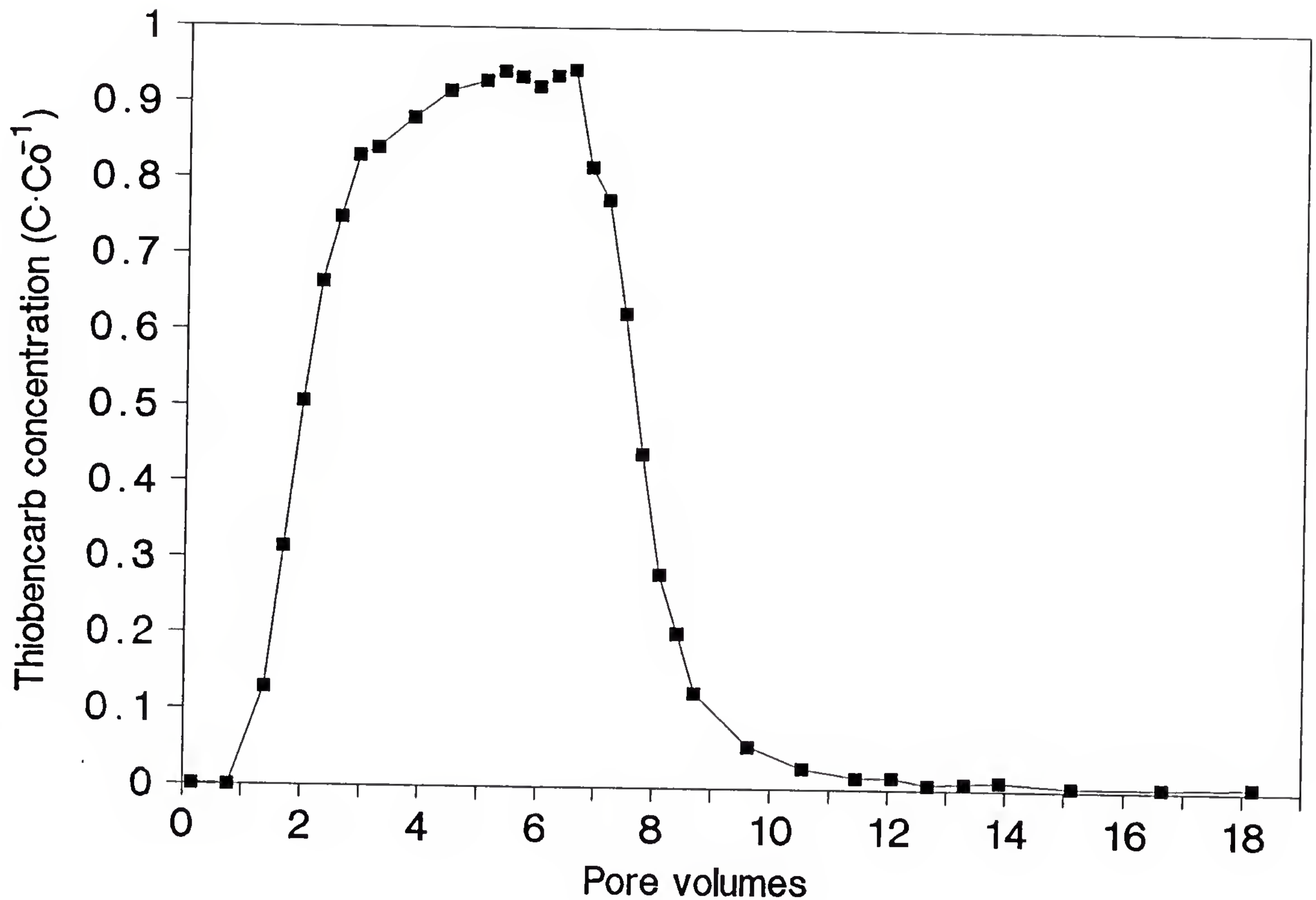

Fig. 2.4. Relative thiobencarb concentration (concentration effluent·initial influent concentration^{-1}) as a function of pore volumes (volume of water contained in saturated soil pores) on an Immokalee sand with a pulse width of 6 pore volumes in 0.01 N $CaCl_2$ with 50 percent by volume methanol.

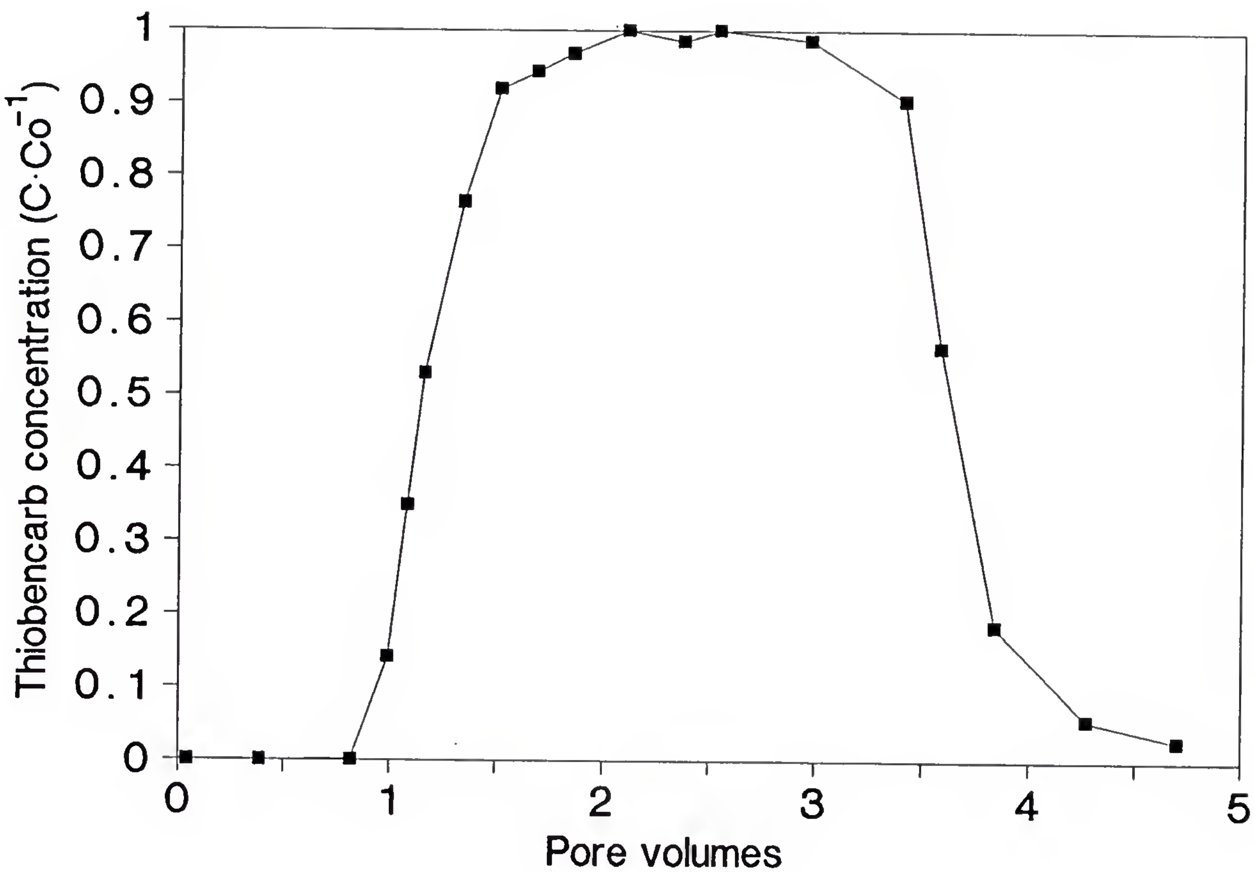

Fig. 2.5. Relative thiobencarb concentration (concentration effluent·initial influent concentration^{-1}) as a function of pore volumes (volume of water contained in saturated soil pores) on an Immokalee sand with a thiobencarb pulse width of 3 pore volumes in 0.01 N $CaCl_2$ with 75 percent by volume methanol.

Table 2.7. Summary of saturated flow (sorption nonequilibrium) parameters estimated by fitting breakthrough curve data on a Immokalee fine sand at different methanol cosolvent fractions.

	Methanol concn. (% by volume)			
Parameter	0	25	50	75
P^z	128	128	128	128
$R_T{}^y$	67.9±1.7	20.0±0.8	1.9±0.2	1.2±0.2

[z]Peclet number (P).
[y]Retardation factor (R_T) followed by its 95% confidence interval.

(an organic solute) desorbed off of soil into the solvent creates a "cavity" in the solvent. The decrease in surface tension of the solvent, due to methanol lowered the energy required to create this solvent cavity, increased the solubility of thiobencarb and caused thiobencarb to remain partitioned into the solution (desorbed) phase (Rao et al., 1986).

Data on the retardation factor values (R_T) at each methanol cosolvent fraction (Table 2.7) were used to calculate the K_f values by the equation:

$$K_f = \frac{(R_T - 1)\Theta}{\rho}$$

where K_f = Freunlich sorption coefficient ($ml \cdot g^{-1}$)

R_T = retardation factor

Θ = volumetric water content ($cm^3 \cdot cm^{-3}$)

ρ = soil bulk density ($g \cdot cm^{-3}$).

These calculated K_f values were plotted versus the percent methanol in the eluting solutions and the log-linear relationship (r^2 = 0.97) is shown in Fig. 2.6. The intercept value (without methanol) when converted from the log form calculated the K_f to be 24.8 (95% C.I. 14.9-41.2) which was similar to the adsorption-desorption isotherm values for an Immokalee sand (Tables 2.3 and 2.4).

Degradation Study

The main effects of temperature, soil-water tension, and soil series on the thiobencarb degradation data are

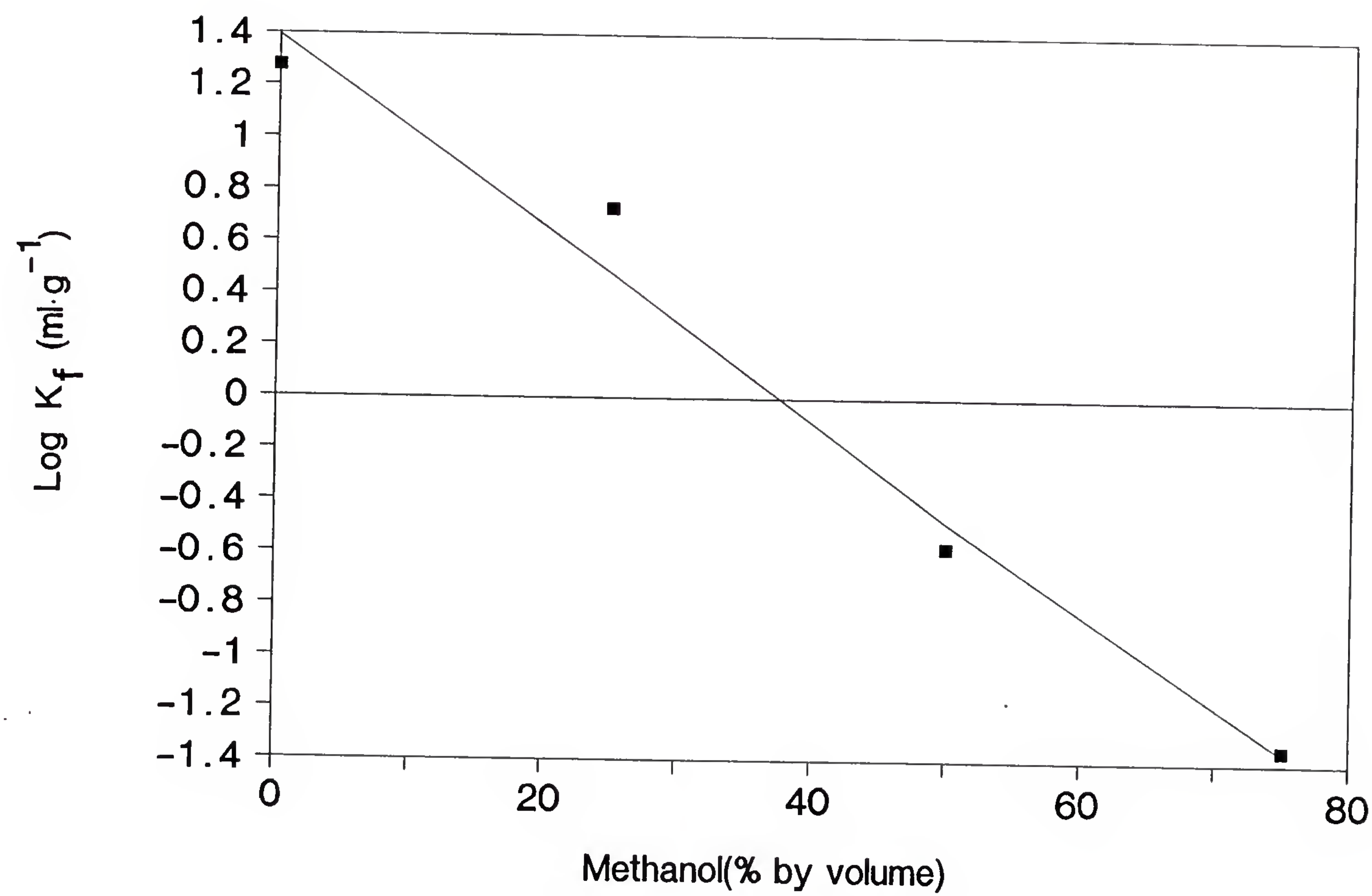

Fig. 2.6. Log-linear relationship between the calculated K_f values (Freundlich adsorption coefficient) and the percent methanol by volume.

shown in Table 2.7. The half-life of thiobencarb was greater with the soil incubated at 25°C than 35°C, and at 100 (drier conditions) than 10 kPa soil-water tension. The half-life of thiobencarb was also affected by soil series.

Soil series, temperature, and soil-water tension interacted in their effects on thiobencarb degradation data (Table 2.8). With the soil incubated at 25°C, the half-life of thiobencarb was similar on the Pahokee and Everglades muck, and was shorter on the mucks than on the Immokalee sand. With the soil incubated at 35°C, the half-life of thiobencarb was longer on the Everglades muck than the Pahokee muck, and was shorter on the mucks than on the Immokalee sand. In all three soils incubated at 25° or 35°C, thiobencarb degraded more rapidly under moist conditions (10 kPa) than dry conditions (100 kPa).

The total amount of ^{14}C recovered from the soils ranged from 97 to 102%. The total recovery was converted to 100% and relative percentages of ^{14}C recovered by extraction, combustion, and as $^{14}CO_2$ were calculated.

The main effects of time of incubation, soil series and temperature significantly affected the percent extractable ^{14}C, bound ^{14}C and $^{14}CO_2$ recovered from soil treated with ^{14}C-labeled thiobencarb (Table 2.9), but soil-water tension had no effect. However, all treatments interacted in their effects on the percentages of

Table 2.7. Main effects of temperature, soil-water tension and soil series on the degradation of thiobencarb.

Treatment	Half-life (da)
Temperature (C) (Temp)	
25	21.4
35	17.7
Signif.[z]	**
Soil-water tension (kPa) (W)	
10	16.7
100	21.4
Signif.	**
Soil series (S)	
Pahokee muck	16.2
Everglades muck	18.5
Immokalee sand	24.1
Signif.	**
Interaction	
Temp × W × S	**

[z]F tests were significant at the 1% (**) level.

Table 2.8. Interaction of soil series, temperature, and soil-water tension on the degradation of thiobencarb.

		Soil series			Contrast[z]	
Temperature (C)	Soil-water tension (kPa)	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
			Half-life (da)			
25	10	16	17	21	NS	**
	100	21	22	33	NS	**
Signif.[y]		**	**	**		
35	10	12	16	19	**	**
	100	16	20	24	**	**
Signif.		**	**	**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level by orthogonal comparison.
[y]F tests were significant at the 1% (**) level.

Table 2.9. Main effect of days of incubation, soil series, temperature, and soil-water tension on the percent extractable, bound, and $^{14}CO_2$ recovered from ^{14}C labeled thiobencarb.

	^{14}C Recovered (%)		
Treatment	Extractable	Bound	$^{14}CO_2$
Days of incubation (D)			
0	67.92	32.07	--
3	83.80	16.08	0.11
7	81.22	18.52	0.25
14	87.11	12.62	0.14
28	83.83	16.08	0.08
42	73.54	26.34	0.11
Signif.[z]	**	**	**
Soil series (S)			
Pahokee muck	66.08	33.68	0.21
Everglades muck	81.70	18.16	0.16
Immokalee sand	90.93	9.01	0.05
Signif.	**	**	**
Temperature (T)			
25°C	81.94	17.93	0.16
35°C	77.20	22.64	0.13
Signif.	**	**	**
Soil-water tension (kPa) (W)			
10	79.07	20.75	0.04
100	80.07	19.82	0.04
Signif.	NS	NS	NS
Interaction			
D × S × T × W	*	*	**

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).

extractable ^{14}C recovered from ^{14}C-thiobencarb treated soil (Table 2.10). With the soil incubated at 25°C and 10 kPa soil-water tension, the percentages of extractable ^{14}C were similar on the Pahokee and Everglades muck soils except at 7 days of incubation, with a greater percentage of extractable ^{14}C recovered from the Everglades than Pahokee muck. With the soil incubated at 25°C and 100 kPa soil-water tension, or incubated at 35°C and 10 or 100 kPa soil-water tension, the percentages of extractable ^{14}C recovered were generally greater from the Everglades than Pahokee muck. The percentages of extractable ^{14}C recovered from the Immokalee sand were generally greater than from the muck soils, but with 42 days of incubation at 100 kPa soil-water tension, the sand and muck soils were similar.

Data on the percentages of bound ^{14}C recovered by soil combustion were affected by the interaction of time of incubation, soil series, temperature, and soil-water tension (Table 2.11), and were inversely proportional to the percentages of extractable ^{14}C recovered. With the soil incubated at 25°C and 10 kPa soil-water tension, the percentages of bound ^{14}C were similar on the Pahokee and Everglades muck soils. However, at 7 days of incubation, greater percentages of bound ^{14}C were recovered from the Pahokee than the Everglades muck. With the soil incubated at 25°C and 100 kPa soil-water tension, or 35°C and 10 or 100 kPa soil-water tension, the percentages of bound

Table 2.10. Interaction of days of incubation, soil series, temperature, and soil-water tension on the percent extractable ^{14}C recovered from ^{14}C labeled thiobencarb.

Soil series	Temperature (C)	Soil-water tension (kPa)	Days of incubation 0	3	7	14	28	42	Signif.[z]
			Extractable ^{14}C recovered (%)						
Pahokee muck (1)	25	10	51	83	59	83	77	69	Qn**
Everglades muck (2)			60	85	91	91	81	70	Qr**
Immokalee sand			89	95	94	97	97	95	NS
Muck 1 vs 2[y]			NS	NS	**	NS	NS	NS	
Muck 1 + 2 vs sand			**	**	**	*	**	**	
Pahokee muck (1)	25	100	51	76	65	82	78	73	Qn**
Everglades muck (2)			77	89	89	90	88	86	C*
Immokalee sand			78	94	96	97	97	76	Qr**
Muck 1 vs 2			**	*	**	NS	*	**	
Muck 1 + 2 vs sand			**	**	**	*	**	NS	
Pahokee muck (1)	35	10	44	74	55	70	65	54	Qn**
Everglades muck (2)			75	80	86	86	83	77	Q**
Immokalee sand			78	90	93	96	96	76	Q**
Muck 1 vs 2			**	NS	**	**	**	**	
Muck 1 + 2 vs sand			**	**	**	**	**	*	
Pahokee muck (1)	35	100	46	66	66	75	66	59	Qn*
Everglades muck (2)			69	79	84	84	83	77	C*
Immokalee sand			97	95	95	96	95	70	C**
Muck 1 vs 2			**	*	**	NS	**	**	
Muck 1 + 2 vs sand			**	**	**	**	**	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were cubic (C), quartic (Qr), or quintic (Qn).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

Table 2.11. Interaction of days of incubation, soil series, temperature, and soil-water tension on the percent bound ^{14}C recovered from ^{14}C labeled thiobencarb.

Soil series	Temperature (C)	Soil-water tension (kPa)	Days of incubation 0	3	7	14	28	42	Signif.[z]
			Bound ^{14}C recovered (%)						
Pahokee muck (1)	25	10	49	17	40	17	22	31	Qn**
Everglades muck (2)			40	15	8	9	18	30	Qr**
Immokalee sand			11	6	6	3	3	5	NS
Muck 1 vs 2[y]			NS	NS	**	NS	NS	NS	
Muck 1 + 2 vs sand			**	**	**	*	**	**	
Pahokee muck (1)	25	100	50	23	35	17	22	27	Qn**
Everglades muck (2)			23	11	11	10	12	13	C**
Immokalee sand			22	7	4	3	3	24	Qr**
Muck 1 vs 2			**	*	**	NS	*	*	
Muck 1 + 2 vs sand			**	**	**	*	**	NS	
Pahokee muck (1)	35	10	56	26	45	29	35	46	Qn**
Everglades muck (2)			25	20	13	13	17	23	Q**
Immokalee sand			22	10	7	4	4	24	Q**
Muck 1 vs 2			**	NS	**	**	**	**	
Muck 1 + 2 vs sand			**	**	**	**	**	*	
Pahokee muck (1)	35	100	54	34	34	25	34	41	Qn*
Everglades muck (2)			31	21	16	16	17	23	C*
Immokalee sand			3	5	5	4	5	30	C**
Muck 1 vs 2			**	*	**	NS	**	**	
Muck 1 + 2 vs sand			**	**	**	**	**	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were quadratic (Q), cubic (C), quartic (Qr), or quintic (Qn).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

^{14}C were generally greater on the Pahokee than Everglades muck. The percentages of bound ^{14}C on the Immokalee sand were generally less than on the muck soils, but with 42 days of incubation at 100 kPa soil-water tension the percentages of bound ^{14}C recovered from the sand and mucks were similar.

Greater amounts of organic matter in the muck soils, lower soil-water tension (10 kPa than 100 kPa) and higher temperatures (35° than 25°C) may have favored microorganisms that degraded thiobencarb (Alexander, 1965; Duah-Yentumi and Kuwatsuka, 1982) thereby shortening the half-life of thiobencarb. The greater percent of extractable ^{14}C recovered from the Immokalee sand was in agreement with the greater amounts of ^{14}C-thiobencarb removed from the sand than the mucks in the desorption study (Table 2.4). Similarly, Katan et al. (1976) found the binding of ^{14}C-parathion residues was dependent on organic matter, and Ambrosi et al. (1977) found that the distribution of ^{14}C-phosalone residues increased in the order fulvic acid > humic acid > humin. The chemical structure of ^{14}C-thiobencarb and ^{14}C-metabolites changed during degradation and mineralization. Each metabolite may have differed in their adsorptive and subsequent extractable characteristics from the muck soils. These differences in adsorption could account for differences in the percentages of extractable

versus bound ^{14}C fractions as the time of incubation increased.

The time of incubation, soil series, temperature, and soil-water tension interacted in their effects on the percent ^{14}C recovered as $^{14}CO_2$ from ^{14}C labeled thiobencarb applied to soil (Table 2.12). The $^{14}CO_2$ accounted for less than 1% of the ^{14}C recovered at any time of incubation or treatment combination. Out of all soil, temperature, and soil-water tension combinations, the greatest $^{14}CO_2$ (0.70%) was recovered from the Pahokee muck at 7 days of incubation. The percentages of ^{14}C recovered as $^{14}CO_2$ from the muck soils were generally greater than that from the Immokalee sand. However, with the soil incubated at 35°C, 100 kPa soil-water tension and 28 days of incubation, $^{14}CO_2$ evolutions were similarly low on all soils.

The primary $^{14}CO_2$ peak at 7 days of incubation in the Pahokee muck was followed by a smaller secondary peak at 42 days of incubation. Ou et al. (1978) found a similar two-peak response with 2,4-D on a Terra Cia muck. The sharp increase in the percent $^{14}CO_2$ at 7 days of incubation coincides with the decrease in the percent extractable ^{14}C and increase in the percent bound ^{14}C found in the soil.

In summarizing the laboratory studies, the strong adsorption and low mobility of thiobencarb indicate that the herbicidal activity of thiobencarb would be low on the

Table 2.12. Interaction of days of incubation, soil series, temperature, and soil-water tension on the percent ^{14}C recovered as $^{14}CO_2$ from ^{14}C labeled thiobencarb.

Soil series	Temperature (C)	Soil-water tension (kPa)	Days of incubation 3	7	14	28	42	Signif.[z]
			$^{14}CO_2$ recovered (%)					
Pahokee muck (1)	25	10	0.14	0.70	0.23	0.14	0.17	Qr**
Everglades muck (2)			0.18	0.20	0.31	0.10	0.17	Qr**
Immokalee sand			0.03	0.08	0.04	0.03	0.04	NS
Muck 1 vs 2[y]			NS	**	*	NS	NS	
Muck 1 + 2 vs sand			**	**	**	**	**	
Pahokee muck (1)	25	100	0.17	0.44	0.21	0.11	0.23	Qr**
Everglades muck (2)			0.13	0.30	0.17	0.10	0.13	Qr**
Immokalee sand			0.03	0.05	0.04	0.03	0.05	NS
Muck 1 vs 2			NS	**	NS	NS	**	
Muck 1 + 2 vs sand			**	**	**	*	**	
Pahokee muck (1)	35	10	0.14	0.33	0.19	0.13	0.15	Qr**
Everglades muck (2)			0.12	0.22	0.13	0.09	0.13	Qr**
Immokalee sand			0.04	0.10	0.08	0.02	0.05	C**
Muck 1 vs 2			NS	**	NS	NS	NS	
Muck 1 + 2 vs sand			**	**	*	**	**	
Pahokee muck (1)	35	100	0.19	0.29	0.14	0.10	0.13	Qr**
Everglades muck (2)			0.12	0.26	0.16	0.09	0.14	Qr**
Immokalee sand			0.09	0.11	0.06	0.04	0.04	L**
Muck 1 vs 2			NS	NS	NS	NS	NS	
Muck 1 + 2 vs sand			*	**	**	NS	**	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS), and were linear (L), cubic (C), or quartic (Qr).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

muck soils and not subject to leaching from rainfall or irrigation. The decrease in thiobencarb adsorption with an increase in methanol concentration indicates that modifications in thiobencarb formulation (surfactants to improve water penetration in soil) may increase thiobencarb activity. This is in agreement with the work of Kumiai (1977). The half-life of thiobencarb, that averaged about 20 days, would probably be too short to provide season-long weed control.

CHAPTER III
WEED CONTROL WITH THIOBENCARB

Literature Review

Weeds reduce the yield and quality of horticultural crops by competing for light, water, and nutrients (Weeds of the No. Cent. U.S., 1981). Weeds also serve as hosts for diseases and insects (Anderson, 1977; Chapman and Carter, 1976). Weed competition studies in transplanted lettuce have shown that the critical weed free period for lettuce is from 3 to 8 weeks (Cerna and Perez, 1980). Cardona et al. (1977) and Appezzato et al. (1983) found that maximum lettuce yields were obtained by maintaining a weed free crop for 3 weeks after transplanting. Garcia (1983) found that in Brazil the weed-free period needed for maximum yields was 1 week for lettuce transplanted from June-August and 3 weeks for lettuce transplanted in October. While there are several herbicides for weed control in lettuce grown on mineral soils (Rozanski et al., 1982; Stall, 1987), presently there are no effective preemergence herbicides recommended for use on muck soils (Stall, 1987). Current chemical weed control recommendations include either the use of glyphosate for stale seed bed preparation or use of paraquat applied

post-directed as a contact herbicide. Hand weeding is used extensively but it is very expensive. Previously CDEC (2-chloroallyl diethyldithiocarbamate) (Guzman and Dusky, 1980; Orsenigo, 1968) and chloropropham (Guzman and Wolf, 1955) were shown to provide effective weed control on muck soils but are no longer registered.

Thiobencarb has primarily been used for weed control in rice (Dusky, 1981; Eastin, 1981; IRRI, 1980; Richard et al., 1981). Thiobencarb also controls weeds in celery (*Apium graveolens* L.), lettuce (*Lactuca sativa* L.), carrots (*Daucus carota* L.) (Dusky, 1982), Indian mustard (*Brassica juncea* Coss.) (Gill, 1982), radishes (*Raphanus sativus* L.) (Dusky, 1984a), snap beans (*Phaseolus vulgaris* L.) (Martinez and Soto, 1978), spinach (*Spinacia oleracea* L.) (Talbert, 1976), table beets (*Beta vulgaris* L.) (Phatak and Cantliffe, 1975), tomatoes (*Lycopersicon esculentum* Mill.) (Abellán, 1979), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) (Imbayashi, 1982) and leather leaf fern (*Rumohra adiantiformis*) (Stamps and Mathur, 1980).

The effectiveness of thiobencarb for the control of broadleaf weeds [primarily spiny amaranth (*Amaranthus spinous* L.) and purslane (*Portulaca oleracea* L.)] in lettuce at 4.5 $kg \cdot ha^{-1}$ preemergence in Florida, Michigan, and Wisconsin muck soils (Dusky, 1984b) ranged from 56 to 96% under varied weather conditions. Gilreath (1984) found

the same rate of thiobencarb to provide only 45 to 52% control of pigweed (Amaranthus hybridus L.) on a Myakka fine sand.

In addition to the variability of thiobencarb to control weeds, crop cultivars may differ in their tolerance to thiobencarb. Reiners et al. (1988) found that 'Dark Green Boston' lettuce was more susceptible to thiobencarb injury and had a greater concentration of ^{14}C labeled thiobencarb in its leaf tissue than 'Great Lakes 366'. Dusky (1984b) found that bibb lettuce was more sensitive to thiobencarb than Boston or crisphead lettuce.

Protectants or safeners can help increase crop tolerance in situations where there is a problem with crop tolerance to herbicides. Activated charcoal applied in the seed row can adsorb herbicide and protect the crop seed from herbicide injury (Locascio, 1967; Ogg, 1982; Richardson and Jones, 1983). Activated charcoal (Horng et al., 1980) or straw ashes (Chang and Mao, 1973) reduced thiobencarb injury to rice. Naphthalic anhydride used as a seed coating prevented phytotoxicity and stand reductions in rice when thiobencarb was applied preplant incorporated (Andrade, 1980). Ruscoe and Moody (undated) found that naphthalic anhydride was useful in reducing thiobencarb injury to rice from a preplant incorporated treatment but not a preemergence treatment.

Materials and Methods

Greenhouse Studies

The effects of soil-water tension, seed protectants, irrigation method, and herbicide application method on the herbicidal activity of thiobencarb were evaluated in greenhouse bioassay studies. In all studies Pahokee muck, Everglades muck, and Immokalee sand soils (Table 2.1) were placed in 27×17×5 cm styrofoam flats and thiobencarb was applied with a backpack sprayer in a 280 liter·ha^{-1} spray volume. Greenhouse conditions were 28°/22°C day/night and 39 E·m^{-2}·day^{-1} photosynthetically active radiation. Visual injury ratings and dry weight data were recorded at 3 weeks after planting. Thiobencarb was applied as a preemergence treatment unless otherwise noted. All data were subjected to ANOVA and means separated by orthogonal comparison.

Soil-water tension study

The effect of soil-water tension on the activity of thiobencarb was evaluated in greenhouse studies. Treatments were factorial combinations of two soil-water tensions, three thiobencarb rates, three soil series (as previously described) and five plant species (Table 3.1). Soil-water tensions were 10 and 100 kPa and thiobencarb rates were 0, 4, and 8 kg·ha^{-1}. Plant species were butterhead and crisphead lettuce (seed were pelleted and unpelleted), barnyardgrass [*Echinochloa crus-galli* (L.) *Beauv.*],

Table 3.1. Seeding rates of plants used in greenhouse bioassay studies.

Plant species	Seed or stolons ($no \cdot 17\ cm^{-1}$)
Butterhead lettuce ('Summer Bibb')	12
Crisphead lettuce ('Fla 49674')	12
Barnyardgrass	15
Purslane	25
Bermudagrass	2 (stolons)

purslane, and bermudagrass [*Cynadon dactylon* (L.) *Pers.*], at 12, 12, 15, 25 seeds, and 2 stolons per flat, respectively. The same seeding rates were used in all greenhouse studies. The treatments were arranged in a randomized completed block design with four replications. Soils were weighed into flats, seeded, and thiobencarb was applied.

Soils were brought to either 10 or 100 kPa soil-water tension gravimetrically and were maintained at that tension for 3 weeks. Soil flats were weighed twice daily and water lost by evaporation was replaced by overhead irrigation. Lettuce and weed plant stands were counted at 3, 7, 14, and 21 DAP.

Protectant study

The effect of chemical protectants on the reduction of thiobencarb injury to lettuce was investigated. Treatments were factorial combinations of two protectants, two thiobencarb rates, three soil series (as previously described), and two lettuce types. Protectant treatments were none, activated charcoal placed on the seed within the seed furrow at 1.4 $g \cdot m^{-1}$ and naphthalic anhydride applied as a seed coating at 0.5% by weight of the lettuce seed. Thiobencarb was applied at 0 or 8 $kg \cdot ha^{-1}$ after the flats were seeded with butterhead and crisphead lettuce. Soil-water tension was maintained at 10 kPa as previously described. Treatment combinations were arranged in a randomized complete block design with four replications.

Irrigation study

The effect of irrigation method on the bioactivity of thiobencarb was investigated. Treatments were factorial combinations of three irrigation methods, three thiobencarb rates, three soil series, and four plant species. Irrigation methods were subsurface, subsurface plus one overhead irrigation or overhead irrigation for the duration of the experiment. Thiobencarb was applied at 0, 4, or 8 $kg \cdot ha^{-1}$ after the flats were seeded with butterhead lettuce, crisphead lettuce, barnyardgrass, and purslane. Each treatment combination was replicated four times in a split-plot design with irrigation method as main plots and thiobencarb rate, soil series, and plant species as subplots. Subsurface and overhead irrigation treatments were separated by placing a barrier of clear polyethylene sheets between irrigation blocks on the greenhouse bench. Subsurface irrigation was applied as needed by placing the flats in plastic trays and filling the trays with water. Holes in the flats allowed the soil to draw up water through capillary action. Overhead irrigation was applied with mist head nozzels at the rate of 0.4 $cm \cdot day^{-1}$.

Thiobencarb placement and irrigation method study

The effect of herbicide application method on the activity of thiobencarb was investigated. Treatments were factorial combinations of two application methods, three irrigation methods, two thiobencarb rates, three soil

series, and three plant species. Pots (3.8 liter) were filled with soil and were treated with 0 or 8 $kg \cdot ha^{-1}$ thiobencarb. The thiobencarb was allowed to remain on the soil surface (preemergence treatment) or incorporated approximately 4.0 cm (preplant incorporated treatment). Irrigation treatments were subsurface irrigation, overhead irrigation for 1.5 weeks followed by subsurface irrigation for 1.5 weeks, or overhead irrigation for 3 weeks. Soil in pots were seeded with crisphead lettuce, barnyardgrass, and purslane either before or after thiobencarb application in the preemergence and preplant incorporated treatments, respectively. Subsurface irrigation was applied as needed by placing the pots in plastic trays and filling the trays with water. Holes in the pots allowed the water to move into the soil by capillary action. Overhead irrigation was applied with mist head nozzels at the rate of 0.4 $cm \cdot day^{-1}$. Each treatment combination was replicated four times in a split-plot design with irrigation method as main plots and thiobencarb application method, soil series, and plant species as subplots.

Field Studies

Thiobencarb application method and lettuce type tolerance to thiobencarb

Experiments were conducted at Zellwood in the Fall of 1987 and at Zellwood and Belle Glade in the Spring of 1988. The soil series were an Everglades muck and Pahokee

muck at Zellwood and Belle Glade sites, respectively. Treatments were factorial combinations of three thiobencarb rates, two thiobencarb application methods, and two lettuce types. Hoed and unhoed treatments were also included. Thiobencarb was applied with a backpack sprayer in a 244 liter·ha^{-1} spray volume with 11004 nozzles at 2, 4, or 8 kg·ha^{-1}. Thiobencarb was applied as a surface preemergence treatment or was preplant incorporated approximately 4.0 cm with a rake. 'FLF 49530' butterhead and 'FLF 44063' crisphead lettuce were seeded with a Planet Jr. Planter. Plots were one bed 6.7 m long × 61 cm wide and were seeded with two rows per bed on 2 Nov. 1987 and 2 Mar. 1988 (Zellwood) and 23 Feb. 1988 (Belle Glade). Treatments were arranged in a randomized complete block design with four replications.

Lettuce stand counts, lettuce vigor, and weed control were evaluated at 3 weeks after planting prior to blocking the lettuce on 30-cm centers within the row. Lettuce was harvested from the center 4.6 m of both rows on 26 Jan. 1988 (Zellwood) and 5 May 1988 (Belle Glade).

Irrigation duration and thiobencarb application method study

Experiments were conducted at Belle Glade in the Fall of 1987 and at Belle Glade and Zellwood in the Spring of 1988. Treatments were factorial combinations of three

irrigation durations and three thiobencarb rates. The irrigation treatments were 1.25 cm of overhead irrigation per day (approximately 2 × pan evaporation) for 0, 4, or 8 days. Thiobencarb was applied at 0, 4, or 8 $kg \cdot ha^{-1}$. Additional treatments of 8 $kg \cdot ha^{-1}$ thiobencarb preplant incorporated, and hoed and unhoed checks were also established. Treatments were arranged in a split-plot design with irrigation duration as main plots and thiobencarb rate as subplots and were replicated four times. 'FLF 44063' crisphead lettuce seed were seeded on two rows per bed 6.7 m long × 61 cm wide on 22 Oct. 1987 and 23 Feb. 1988 (Belle Glade) and 2 Mar. 1987 (Zellwood).

Lettuce stand counts, lettuce vigor, weed control ratings, weed stand counts, and weed biomass (dry weight) were evaluated at 3 weeks after planting, prior to blocking. Lettuce was harvested on 6 Jan. and 6 May 1988 in Belle Glade. The total number of heads and number and weight of marketable heads were recorded.

In 1988 lettuce in all treatments that received thiobencarb in the lettuce type and irrigation studies were hoed 3 weeks after planting to evaluate thiobencarb toxicity without the confounding effects of weed competition. Data from field experiments were subjected to ANOVA and means separated by orthogonal comparison.

Results and Discussion

Greenhouse Studies

Soil-water tension study. The main effects of thiobencarb rate, soil series, soil-water tension and time after planting on lettuce and weed plant stand data are shown in Table 3.2. Butterhead lettuce plant stands decreased linearly from 10 to 8 plants$\cdot$flat^{-1} as time after planting increased from 3 to 21 days after planting (DAP). Pelleted butterhead lettuce plant stands were similar from 3 to 21 DAP. Crisphead lettuce (unpelleted and pelleted) plant stands decreased from 10 to 8 plants $\cdot$flat^{-1} from 3 to 7 DAP and to 6 plants$\cdot$flat^{-1} at 14 and 21 DAP. Barnyardgrass plant stands (12 plants$\cdot$flat^{-1}) were the same at 3 and 7 DAP, but decreased to 9 plants$\cdot$flat^{-1} 14 DAP and the same plant stand was maintained at 21 DAP. Purslane plant stands decreased from 17 to 12 plants$\cdot$flat^{-1} from 3 to 21 DAP. Bermudagrass plant stand increased from 0 at 3 DAP to 1 plant$\cdot$flat^{-1} at 7 DAP and remained at 1 plant$\cdot$flat^{-1} through the remainder of the experiment.

Butterhead lettuce plant stand decreased from 10 plants$\cdot$flat^{-1} without thiobencarb to 9 plants$\cdot$flat^{-1} with 4 kg$\cdot$ha^{-1} of thiobencarb. With a further increase in thiobencarb rate to 8 kg$\cdot$ha^{-1} butterhead lettuce plant stand decreased to 7 plants$\cdot$flat^{-1}. Pelleted butterhead lettuce plant stands were not affected by thiobencarb rate. Unpelleted crisphead lettuce plant stands decreased

Table 3.2. Main effect of lettuce and weed stand as affected by time after planting, thiobencarb rate, soil series, and soil-water tension in greenhouse studies.

Treatment	Lettuce (no.•flat^{-1})				Weeds (no.•flat^{-1})		
	Butter-head	Butterhead (pelleted)	Crisp-head	Crisphead (pelleted)	Barnyard-grass	Purslane	Bermuda-grass
Time after planting (da)							
3	10	7	10	10	12	17	0
7	9	7	8	8	12	13	1
14	8	5	6	6	9	12	1
21	8	5	6	6	9	12	1
Signif.[z]	L**	NS	Q**	Q*	L**	L*	Q**
Thiobencarb rate (kg•ha^{-1})(T)							
0	10	6	9	9	13	19	1
4	9	5	8	8	10	11	1
8	7	6	7	6	7	9	1
Signif.	Q*	NS	L**	L**	L*	L**	NS
Soil series (S)							
Pahokee muck (1)	11	6	9	10	13	16	1
Everglades muck (2)	9	6	8	8	10	14	1
Immokalee sand	7	5	6	6	8	9	1
Contrast[y]							
Muck 1 vs 2	**	NS	**	**	NS	**	NS
Muck 1 + 2 vs sand	**	*	**	**	*	**	NS
Soil-water tension (kPa)(W)							
10	10	6	8	9	12	8	1
100	8	5	7	7	12	9	1
Signif.	**	NS	*	**	NS	NS	NS

Table 3.2--continued.

Treatment	Lettuce (no˜•flat^{-1})				Weeds (no.•flat^{-1})		
	Butter-head	Butterhead (pelleted)	Crisp-head	Crisphead (pelleted)	Barnyard-grass	Purslane	Bermuda-grass
Interaction							
Time × T	NS	NS	NS	NS	**	NS	NS
Time × S	NS	NS	NS	**	**	*	NS
Time × T × S	**	NS	**	NS	NS	*	NS
Time × T × W	**	NS	*	**	NS	NS	NS

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

linearly from 9 to 7 plants$\cdot$flat^{-1} and for pelleted crisphead lettuce from 9 to 6 plants$\cdot$flat^{-1}, as thiobencarb rate increased from 0 to 8 kg$\cdot$ha^{-1}. Barnyardgrass plant stands decreased linearly from 13 to 7 plants$\cdot$flat^{-1} and purslane plant stands decreased linearly from 19 to 9 plants$\cdot$flat^{-1} as thiobencarb rate increased from 0 to 8 kg$\cdot$ha^{-1}. Bermudagrass plant stands were not affected by thiobencarb rate.

Butterhead, crisphead and crisphead pelleted lettuce, and purslane plant stands were higher on the Pahokee muck than on the Everglades muck and the mean plant stands of the muck soils were higher than on the Immokalee sand. The pelleted butterhead lettuce and barnyardgrass plant stands were similar on both mucks and was higher than the stand on the Immokalee sand. Bermudagrass plant stand was 1 plant$\cdot$flat^{-1} in all soils.

Butterhead, crisphead, and pelleted crisphead lettuce plant stands were greater with 10 kPa than with 100 kPa soil-water tension. Pelleted butterhead lettuce, barnyardgrass, purslane, and bermudagrass plant stands were not affected by soil-water tension.

Butterhead lettuce plant stands were affected by an interaction between time after planting, thiobencarb rate, and soil series (Table 3.3). On the Pahokee muck, butterhead lettuce plant stands were similar from 3 to

Table 3.3. Interaction of time after planting, soil series, and thiobencarb rate on butterhead lettuce stand in greenhouse studies.

Soil series	Thiobencarb ($kg \cdot ha^{-1}$)	3	7	14	21	Signif.[z]
		Butterhead lettuce ($no. \cdot flat^{-1}$)				
Pahokee muck						
	0	11	10	10	10	NS
	4	11	11	10	10	NS
	8	12	12	12	12	NS
Signif.		NS	L**	L**	L*	
Everglades muck						
	0	10	11	11	11	NS
	4	12	11	8	8	L**
	8	9	7	5	5	Q*
Signif.		Q**	Q**	L**	L**	
Immokalee sand						
	0	12	11	7	7	Q*
	4	12	9	5	5	Q**
	8	8	2	0	0	C**
Signif.		Q**	Q**	Q*	Q*	

Treatment: Soil series, Thiobencarb; Time after planting (da): 3, 7, 14, 21.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

21 DAP with all rates of thiobencarb. With 4 $kg \cdot ha^{-1}$ of thiobencarb on the Everglades muck, butterhead lettuce plant stand decreased linearly from 12 to 8 $plants \cdot flat^{-1}$ as time increased from 3 to 21 DAP. With 8 $kg \cdot ha^{-1}$ thiobencarb, butterhead lettuce plant stand decreased quadratically (9, 7, 5 and 5 $plants \cdot flat^{-1}$) as DAP increased (3, 7, 14 and 21 DAP, respectively). On the Immokalee sand, butterhead lettuce stand decreased from 12 to 7 $plants \cdot flat^{-1}$ as time after planting increased from 3 to 21 DAP in the absence of thiobencarb. With 4 $kg \cdot ha^{-1}$ of thiobencarb, the butterhead lettuce stand decreased quadratically (12, 9, 5 and 5 $plants \cdot flat^{-1}$) as DAP increased from 3 to 21 days. With an increase in the thiobencarb rate to 8 $kg \cdot ha^{-1}$, butterhead lettuce stand decreased from 8 to 0 $plants \cdot flat^{-1}$ as time increased from 3 to 14 DAP.

Butterhead lettuce plant stands were affected by an interaction between time after planting, thiobencarb rate, and soil-water tension (Table 3.4). Butterhead lettuce stands decreased linearly from 12 to 10 $plants \cdot flat^{-1}$ as time increased from 3 to 21 DAP when no thiobencarb was applied and soil-water tension was maintained at 10 kPa but were similar as DAP increased with 100 kPa soil-water tension. Butterhead lettuce stands were similar as DAP increased with 4 $kg \cdot ha^{-1}$ of thiobencarb and soil-water tension was 10 kPa, but with 100 kPa soil-water tension, butterhead lettuce stand decreased quadratically

Table 3.4. Interaction of time after planting, thiobencarb rate, and soil-water tension on butterhead lettuce stand in greenhouse studies.

Treatment: Thiobencarb ($kg \cdot ha^{-1}$)	Treatment: Soil-water tension (kPa)	Time after planting (da): 3	7	14	21	Signif.[z]
		Butterhead lettuce ($no. \cdot flat^{-1}$)				
0	10	12	11	10	10	L**
	100	10	10	9	9	NS
Signif.		**	NS	NS	NS	
4	10	12	12	11	11	NS
	100	11	9	6	6	Q**
Signif.		NS	**	**	**	
8	10	10	7	5	5	Q**
	100	9	7	6	6	Q*
Signif.		NS	NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

(11, 9, 6, and 6 plants$\cdot$flat^{-1}) as DAP increased (3, 7, 14, and 21 DAP). Butterhead lettuce stand with 8 kg$\cdot$ha^{-1} of thiobencarb decreased quadratically as DAP increased with 10 or 100 kPa soil-water tension.

Crisphead lettuce stands were affected by an interaction of time after planting, thiobencarb rate, and soil series (Table 3.5). Crisphead lettuce stands on Pahokee muck were similar from 3 to 21 DAP. On the Everglades muck soil, crisphead lettuce stands were similar from 7 to 21 DAP when no thiobencarb was applied, but with 4 kg$\cdot$ha^{-1} of thiobencarb, crisphead lettuce stand decreased linearly from 11 to 6 plants$\cdot$flat^{-1} from 3 to 21 DAP. Crisphead lettuce stand decreased quadratically (10, 7, 4, and 4 plants$\cdot$flat^{-1}) as time increased (3, 7, 14, and 21 DAP) with 8 kg$\cdot$ha^{-1} of thiobencarb. On the Immokalee sand, crisphead lettuce stand decreased linearly from 10 to 7 plants$\cdot$flat^{-1} as DAP increased from 3 to 21 DAP with no thiobencarb. With 4 kg$\cdot$ha^{-1} of thiobencarb, crisphead lettuce stand decreased quadratically (11, 7, 4, and 4 plants$\cdot$flat^{-1}) as DAP increased (3, 7, 14, and 21 DAP). With 8 kg$\cdot$ha^{-1} of thiobencarb, the crisphead lettuce stands were similar at 3 and 7 DAP (7 and 8 plants$\cdot$flat^{-1}), decreased to 0 plants$\cdot$flat^{-1} at 14 DAP, and remained at 0 plants$\cdot$flat^{-1} at 21 DAP.

Time after planting, thiobencarb rate, and soil-water tension interacted in their effects on crisphead lettuce

Table 3.5. Interaction of time after planting, thiobencarb rate, and soil series on crisphead lettuce stand in greenhouse studies.

Treatment: Soil series	Treatment: Thiobencarb ($kg \cdot ha^{-1}$)	Time after planting (da): 3	7	14	21	Signif.[z]
		Crisphead lettuce ($no. \cdot flat^{-1}$)				
Pahokee muck						
	0	9	8	7	7	NS
	4	9	10	10	10	NS
	8	10	10	10	10	NS
Signif.		NS	NS	L**	L**	
Everglades muck						
	0	11	10	9	9	NS
	4	11	10	6	6	L**
	8	10	7	4	4	Q**
Signif.		NS	L**	L**	L**	
Immokalee sand						
	0	10	10	7	7	L**
	4	11	7	4	4	Q**
	8	7	8	0	0	C**
Signif.		Q**	Q*	L**	L**	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

stand (Table 3.6). Crisphead lettuce stands were similar from 3 to 21 DAP with no thiobencarb, and soil-water tension was 10 kPa. With soil-water tension increased to 100kPa (a drier condition), crisphead lettuce stands decreased linearly from 10 to 7 plants•flat^{-1} from 3 to 21 DAP. Crisphead lettuce stands decreased linearly from 10 to 9 plants•flat^{-1} from 3 to 21 DAP with 4 kg•ha^{-1} of thiobencarb and soil-water tension at 10 kPa. With soil-water tension increased to 100 kPa crisphead lettuce stand decreased quadratically (10, 8, 5, and 5 plants•flat^{-1}) from 3 to 21 DAP. With 8 kg•ha^{-1} thiobencarb and 10 kPa soil-water tension, crisphead lettuce stands decreased quadratically (10, 6, 4, and 4 plants•flat^{-1}) from 3 to 21 DAP. With soil-water tension at 100 kPa crisphead lettuce stands decreased cubically (10, 6, 5, and 5 plants•flat^{-1}) as DAP increased (3, 7, 14, and 21 DAP). With 8 kg•ha^{-1} of thiobencarb, crisphead lettuce stand was not affected by soil-water tension.

Pelleted crisphed lettuce stands were affected by an interaction between time after planting and soil series (Table 3.7). Pelleted crisphead lettuce stands were the same (10 plants•flat^{-1}) on the Pahokee muck soil from 3 to 21 DAP. Pelleted crisphead lettuce stand decreased as DAP increased on the Everglades muck and Immokalee sand.

An interaction of time after planting, thiobencarb rate, and soil-water tension affected pelleted crisphead

Table 3.6. Interaction of time after planting, thiobencarb rate, and soil-water tension on crisphead lettuce stand in greenhouse studies.

Treatment: Thiobencarb ($kg \cdot ha^{-1}$)	Treatment: Soil-water tension (kPa)	Time after planting (da): 3	7	14	21	Signif.[z]
		Crisphead lettuce ($no. \cdot flat^{-1}$)				
0	10	10	10	9	9	NS
	100	10	9	7	7	L**
Signif.		NS	NS	*	*	
4	10	10	11	9	9	L*
	100	10	8	5	5	Q**
Signif.		NS	**	**	**	
8	10	10	6	4	4	Q**
	100	10	6	5	5	C*
Signif.		NS	NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

Table 3.7. Interaction of time after planting and soil series on crisphead (pelleted) lettuce stand in greenhouse studies.

Soil series	Time after planting (da) 3	7	14	21	Signif.[z]
	Crisphead (pelleted) lettuce ($no. \cdot flat^{-1}$)				
Pahokee muck (1)	10	10	10	10	NS
Everglades muck (2)	10	8	6	6	Q**
Immokalee sand	10	6	3	3	Q**
Contrast[y]					
Muck 1 vs 2	NS	**	**	**	
Muck 1 + 2 vs sand	NS	**	**	**	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS) and were quadratic (Q).
[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

lettuce stand (Table 3.8). Pelleted crisphead lettuce stands were similar at 10 and 100 kPa soil-water tension from 3 to 21 DAP with 0 or 8 $kg \cdot ha^{-1}$, but were greater with 10 kPa soil-water tension with 4 $kg \cdot ha^{-1}$ thiobencarb from 7 to 21 DAP.

Barnyardgrass stands were affected by an interaction of time after planting and soil series (Table 3.9). On the Pahokee muck, barnyardgrass stands were similar from 3 to 21 DAP. Barnyardgrass stands decreased cubically on the Everglades muck (12, 13, 8, and 8 $plants \cdot flat^{-1}$) and on the Immokalee sand (11, 11, 5, and 5 $plants \cdot flat^{-1}$) as time increased from 3 to 21 DAP. Barnyardgrass stands were also affected by an interaction of thiobencarb rate and time after planting. Barnyardgrass stands were similar at 3 to 21 DAP with no thiobencarb, decreased quadratically with 4 $kg \cdot ha^{-1}$ of thiobencarb (13, 12, 8, and 8 plants $\cdot flat^{-1}$), and decreased cubically with 8 $kg \cdot ha^{-1}$ of thiobencarb (10, 11, 4, and 4 $plants \cdot flat^{-1}$) as DAP increased (3, 7, 14, and 21 DAP).

Data on the interaction of time after planting, soil series, and thiobencarb rate on purslane stand are shown in Table 3.10. As time increased from 3 to 21 DAP, purslane stands were similar on the Pahokee muck with no thiobencarb but decreased from 18 to 12 $plants \cdot flat^{-1}$ with 4 $kg \cdot ha^{-1}$ thiobencarb. With 8 $kg \cdot ha^{-1}$ thiobencarb, purslane stands decreased from 19 to 13 $plants \cdot flat^{-1}$ as DAP increased from 3 to 21. Purslane stands were similar from 3 to 21 DAP on

Table 3.8. Interaction of time after planting, thiobencarb rate and soil-water tension on crisphead (pelleted) lettuce stand in greenhouse studies.

Treatment: Thiobencarb ($kg \cdot ha^{-1}$)	Treatment: Soil-water tension (kPa)	Time after planting (da): 3	7	14	21	Signif.[z]
		Crisphead (pelleted) lettuce ($no. \cdot flat^{-1}$)				
0	10	11	11	9	9	L*
	100	10	9	7	7	L**
Signif.		NS	NS	NS	NS	
4	10	11	10	9	9	L*
	100	11	7	4	4	Q**
Signif.		NS	**	**	**	
8	10	8	7	4	4	L**
	100	9	5	5	5	Q**
Signif.		NS	NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

Table 3.9. Interaction of time after planting and soil series, and time and thiobencarb rate on barnyardgrass stand in greenhouse studies.

Treatment	Time after planting (da)				
	3	7	14	21	Signif.[z]
	Barnyardgrass (no.•flat^{-1})				
Soil series					
Pahokee muck (1)	13	13	12	12	NS
Everglades muck (2)	12	13	8	8	C**
Immokalee sand	11	11	5	5	C**
Contrast[y]					
Muck 1 vs 2	NS	NS	**	**	
Muck 1 + 2 vs sand	NS	*	**	**	
Thiobencarb (kg•ha^{-1})					
0	12	13	13	13	NS
4	13	12	8	8	Q**
8	10	11	4	4	C**
Signif.	Q*	L*	L**	L**	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

Table 3.10. Interaction of time after planting, soil series and thiobencarb rate on purslane stand in greenhouse studies.

Treatment		Time after planting (da)				
Soil series	Thiobencarb ($kg \cdot ha^{-1}$)	3	7	14	21	Signif.[z]
		Purslane ($no. \cdot flat^{-1}$)				
Pahokee muck						
	0	19	16	16	16	NS
	4	18	16	12	12	L*
	8	19	17	13	13	L*
Signif.		NS	NS	NS	NS	
Everglades muck						
	0	21	20	20	20	NS
	4	16	18	11	11	L**
	8	13	6	6	6	Q*
Signif.		L**	Q*	L**	L**	
Immokalee sand						
	0	20	21	20	20	NS
	4	18	1	2	2	C**
	8	9	0	0	0	Q*
Signif.		L**	Q**	Q**	Q**	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

Everglades muck soil with no thiobencarb and decreased linearly from 16 to 11 plants·flat^{-1} with 4 kg·ha^{-1} thiobencarb as DAP increased from 3 to 21. With a further increase to 8 kg·ha^{-1} thiobencarb, the purslane stands decreased quadratically (13, 6, 6, and 6 plants·flat^{-1}) at 3, 7, 14, and 21 DAP, respectively. Purslane stands were similar from 3 to 21 DAP on the Immokalee stand with no thiobencarb, decreased cubically with 4 kg·ha^{-1} of thiobencarb (18, 1, 2, and 2 plants·flat^{-1}), and decreased quadratically with 8 kg·ha^{-1} of thiobencarb (9, 0, 0, and 0 plants·flat^{-1}) as DAP increased (3, 7, 14, and 21 DAP).

Data on the main effects of thiobencarb rate, soil series, and soil-water tension on lettuce vigor and weed control ratings are shown in Table 3.11. Butterhead lettuce vigor ratings decreased quadratically (100, 55, and 26%) as thiobencarb rate increased from 0 to 8 kg·ha^{-1}. Pelleted butterhead, crisphead, and pelleted crisphead lettuce vigor ratings decreased linearly as thiobencarb rate increased from 0 to 8 kg·ha^{-1}. Barnyardgrass, purslane, and bermudagrass control ratings increased sharply as thiobencarb rate increased from 0 to 4 kg·ha^{-1} and increased slightly with a further increase to 8 kg·ha^{-1} thiobencarb.

Butterhead lettuce vigor, and barnyardgrass and purslane control ratings were similar on the Pahokee muck (67%) and Everglades muck (71%) but the mean stands were

Table 3.11. Main effect of thiobencarb rate, soil series, and soil-water tension on lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Treatment	Lettuce vigor (%)				Weed control (%)		
	Butter-head	Butterhead (pelleted)	Crisp-head	Crisphead (pelleted)	Barnyard-grass	Purslane	Bermuda-grass
Thiobencarb rate ($kg \cdot ha^{-1}$)(T)							
0	100	100	100	100	0	0	0
4	55	61	63	63	68	81	30
8	26	26	28	30	80	90	34
Signif.[z]	Q**	L**	L**	L**	Q**	Q**	Q**
Soil series (S)							
Pahokee muck (1)	67	68	71	70	51	53	20
Everglades muck (2)	71	76	78	81	30	51	18
Immokalee sand	43	44	43	42	66	66	26
Contrast[y]							
Muck 1 vs 2	NS	**	**	**	NS	NS	NS
Muck 1 + 2 vs sand	**	**	**	**	**	**	NS
Soil-water tension (kPa)(W)							
10	65	67	68	68	49	58	28
100	56	58	59	61	49	56	14
Signif.	**	**	**	**	NS	*	*
Interactions							
T × S	**	**	**	**	**	**	NS
T × W	NS	NS	NS	NS	NS	NS	*
S × W	**	**	**	**	NS	**	NS
T × S × W	**	*	*	*	NS	**	NS

Table 3.11--continued.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

greater on the mucks than on the Immokalee sand (43%) (Table 3.11). Pelleted butterhead, crisphead and pelleted crisphead lettuce vigor ratings were greater on the Everglades muck than the Pahokee muck and the mean lettuce vigor ratings on the mucks were greater than on the Immokalee sand. Barnyardgrass and purslane control ratings were similar on the Pahokee muck and the Everglades muck, but barnyardgrass and purslane control ratings on the mucks were less than on the Immokalee sand. Bermudagrass control ratings were not affected by soil series. Butterhead, pelleted butterhead, crisphead, and pelleted crisphead lettuce vigor ratings at 10 kPa soil-water tension (65, 67, 68, and 68%) were greater than at 100 kPa soil-water tension (56, 58, 59, and 61%). Barnyardgrass control was not affected by soil-water tension. Purslane and bermudagrass control ratings were greater at 10 kPa soil-water tension than at 100 kPa.

Thiobencarb rate and soil series interacted in their effects on barnyardgrass control ratings and thiobencarb rate and soil-water tension interacted in their effects on bermudagrass control ratings (Table 3.12). Barnyardgrass control ratings on the Pahokee muck increased quadratically (0, 71, and 83%) as thiobencarb rate increased (0, 4, and 8 $kg{\cdot}ha^{-1}$). Barnyardgrass control ratings on the Everglades muck increased linearly from 0 to 57% as thiobencarb rate

Table 3.12. Interaction of thiobencarb rate and soil series, and thiobencarb rate and soil-water tension on weed control in greenhouse studies at 21 days after planting.

Treatment	Thiobencarb ($kg \cdot ha^{-1}$) 0	4	8	Signif.[z]
Soil series	Barnyardgrass control (%)			
Pahokee muck (1)	0	71	83	Q**
Everglades muck (2)	0	34	57	L**
Immokalee sand	0	99	99	Q**
Contrast[y]				
Muck 1 vs 2	NS	**	**	
Muck 1 + 2 vs sand	NS	**	**	
Soil-water tension (kPa)	Bermudagrass control (%)			
10	0	33	10	Q**
100	0	34	50	L**
Signif.	NS	NS	**	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS) and were linear (L) or quadratic (Q).
[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

increased from 0 to 8 $kg \cdot ha^{-1}$. Barnyardgrass control ratings on the Immokalee sand increased from 0 to 99% as thiobencarb rate increased (0 to 4 $kg \cdot ha^{-1}$) with no further increase in control with 8 $kg \cdot ha^{-1}$. Bermudagrass control ratings at 10 kPa soil-water tension were 0, 33, and 10% with applications of 0, 4, and 8 $kg \cdot ha^{-1}$ thiobencarb, respectively and increased linearly from 0 to 50% at 100 kPa soil-water tension as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$.

Thiobencarb rate, soil series and soil-water tension interacted in their effects on lettuce vigor and weed control ratings (Table 3.13). On the Pahokee muck, the vigor of all lettuce types decreased about 20% as the thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$ and decreased an additional 60% with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb. On the Everglades muck, butterhead, pelleted butterhead, crisphead, and pelleted crisphead lettuce vigor ratings decreased linearly from 100 to about 67% as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$ with 10 kPa soil-water tension. Butterhead and pelleted butterhead lettuce vigor decreased from 100 to about 25%, and crisphead and pelleted crisphead lettuce vigor ratings decreased from 100 to about 40% as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$ with 100 kPa soil-water tension. On the Immokalee sand, butterhead, pelleted butterhead, crisphead, and pelleted crisphead lettuce vigor

Table 3.13. Interaction of thiobencarb rate, soil series, and soil-water tension on lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Soil-water tension (kPa)	Pahokee muck				Everglades muck				Immokalee sand			
	Thiobencarb ($kg \cdot ha^{-1}$)											
	0	4	8	Signif.[z]	0	4	8	Signif.	0	4	8	Signif.
	Butterhead lettuce vigor (%)											
10	100	73	21	L**	100	78	63	L**	100	24	22	Q**
100	100	85	24	Q**	100	58	27	L**	100	13	2	Q**
Signif.	NS	**	**		NS	**	**		NS	**	**	
	Butterhead lettuce (pelleted) vigor (%)											
10	100	80	21	Q**	100	88	66	L**	100	21	26	Q**
100	100	88	18	Q**	100	78	24	Q**	100	13	3	Q**
Signif.	NS	NS	NS		NS	*	**		NS	NS	**	
	Crisphead lettuce vigor (%)											
10	100	86	24	Q**	100	89	66	L**	100	28	16	Q**
100	100	90	23	Q**	100	73	38	L**	100	11	1	Q**
Signif.	NS	NS	NS		NS	**	**		NS	**	**	
	Crisphead lettuce (pelleted) vigor (%)											
10	100	90	19	Q**	100	88	73	L**	100	23	17	Q**
100	100	90	24	Q**	100	78	45	L**	100	11	1	Q**
Signif.	NS	NS	NS		NS	NS	**		NS	*	**	
	Purslane control (%)											
10	0	76	93	Q**	0	68	83	Q**	0	99	99	Q**
100	0	64	86	Q**	0	77	79	Q**	0	100	99	Q**
Signif.	NS	**	*		NS	**	NS		NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

ratings decreased from 100 to about 20% with an increase in thiobencarb from 0 to 4 $kg \cdot ha^{-1}$ and were similar with a further increase to 8 $kg \cdot ha^{-1}$ with 10 kPa soil-water tension. With 100 kPa soil-water tension, the vigor ratings of all lettuce types decreased from 100 to about 12% with 4 $kg \cdot ha^{-1}$ thiobencarb and decreased to about 2% with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb. Purslane control increased sharply on all soils with an increase in thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ and increased slightly more with an increase from 4 to 8 $kg \cdot ha^{-1}$ thiobencarb.

The main effects of thiobencarb rate, soil series, and soil-water tension on plant dry weight data are shown in Table 3.14. Butterhead, pelleted butterhead, crisphead, and pelleted crisphead lettuce dry weights decreased from 340 to about 230 mg as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. Barnyardgrass dry weights decreased sharply with an increase in thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ and decreased slightly more with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb. Purslane dry weights decreased linearly from 108 to 41 mg as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. Bermudagrass dry weight was not affected by thiobencarb rate, soil series, and soil-water tension. Dry weights of all lettuce types, and purslane were higher on the Everglades muck than on the Pahokee muck, and with moist soil (10 kPa) than dry soil (100 kPa), but barnyardgrass was not affected.

Table 3.14. Main effect of thiobencarb rate, soil series, and soil-water tension on plant dry weight in greenhouse studies at 21 days after planting.

Treatment	Lettuce dry wt ($mg \cdot flat^{-1}$)				Weed dry wt ($mg \cdot flat^{-1}$)		
	Butter-head	Butterhead (pelleted)	Crisp-head	Crisphead (pelleted)	Barnyard-grass	Purslane	Bermuda-grass
Thiobencarb rate ($kg \cdot ha^{-1}$)(T)							
0	362	311	343	335	299	108	169
4	261	271	311	286	85	86	103
8	244	216	215	241	45	41	105
Signif.[z]	L**	L**	L**	L*	Q**	L*	NS
Soil series (S)							
Pahokee muck (1)	180	180	204	256	137	52	148
Everglades muck (2)	405	380	444	407	205	141	135
Immokalee sand	281	238	217	202	87	42	93
Contrast[y]							
Muck 1 vs 2	**	**	**	**	**	**	NS
Muck 1 + 2 vs sand	NS	NS	**	**	**	*	NS
Soil-water tension (kPa)(W)							
10	358	344	357	387	154	47	122
100	220	188	228	238	132	109	129
Signif.	**	**	**	**	NS	*	NS
Interactions							
T × S	**	*	**	**	**	NS	NS
S × W	**	**	**	**	**	NS	NS
T × S × W	NS	NS	NS	NS	**	NS	NS

Table 3.14--continued.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS), and were linear (L) or quadratic (Q).

[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

Thiobencarb rate and soil series interacted in their effects on lettuce dry weight (Table 3.15). On the Pahokee and Everglades muck, lettuce dry weights (all types) were not affected by thiobencarb rate. On the Immokalee sand, butterhead lettuce dry weight decreased sharply as thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$ and decreased slightly with an additional increase from 4 to 8 $kg \cdot ha^{-1}$ thiobencarb. Pelleted butterhead lettuce, crisphead lettuce, and pelleted crisphead lettuce dry weights decreased linearly as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$ on the Immokalee sand.

Soil series and soil-water tension interacted in their effects on lettuce dry weight (Table 3.16). Lettuce dry weights (all lettuce types) on the Pahokee muck soil were not affected by soil-water tension. On the Everglades muck and Immokalee sand, lettuce dry weights were greater in the moist soil (10 kPa) than the dry soil (100 kPa).

Thiobencarb rate, soil series and soil-water tension interacted in their effects on barnyardgrass dry weight (Table 3.17). Barnyardgrass dry weights on the Pahokee muck decreased from 220 to 98 mg with 10 kPa and from 241 to 33 mg with 100 kPa soil-water tension as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. On the Everglades muck at 10 kPa soil-water tension, barnyardgrass dry weights

Table 3.15. Interaction of thiobencarb rate and soil series on lettuce dry weight in greenhouse studies at 21 days after planting.

Thiobencarb (kg·ha^{-1})	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
	Butterhead lettuce dry wt (mg·flat^{-1})				
0	228	393	465	**	**
4	149	412	222	**	NS
8	164	410	158	**	**
Signif.[y]	NS	NS	Q*		
	Butterhead (pelleted) lettuce dry wt (mg·flat^{-1})				
0	224	366	345	**	NS
4	181	433	200	**	**
8	137	343	169	**	NS
Signif.	NS	NS	L**		
	Crisphead lettuce dry wt (mg·flat^{-1})				
0	212	439	380	**	NS
4	232	481	211	**	*
8	167	412	60	**	**
Signif.	NS	NS	L**		
	Crisphead (pelleted) lettuce dry wt (mg·flat^{-1})				
0	264	383	385	**	NS
4	253	435	170	**	**
8	249	404	70	**	**
Signif.	NS	NS	L**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level; differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

Table 3.16. Interaction of soil series and soil-water tension on lettuce dry weight in greenhouse studies at 21 days after planting.

Soil-water tension (kPa)	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
	Butterhead lettuce dry wt ($mg \cdot flat^{-1}$)				
10	190	486	398	**	NS
100	171	324	166	**	**
Signif.[y]	NS	**	**		
	Butterhead (pelleted) lettuce dry wt ($mg \cdot flat^{-1}$)				
10	203	484	397	**	NS
100	158	277	128	**	**
Signif.	NS	**	**		
	Crisphead lettuce dry wt ($mg \cdot flat^{-1}$)				
10	194	579	272	**	**
100	213	310	161	**	**
Signif.	NS	**	**		
	Crisphead (pelleted) lettuce dry wt ($mg \cdot flat^{-1}$)				
10	273	602	276	**	**
100	240	346	129	**	**
Signif.	NS	**	**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level; differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 1% (**) level or nonsignificant (NS).

Table 3.17. Interaction of thiobencarb rate, soil series and soil-water tension on barnyardgrass dry weight in greenhouse studies at 21 days after planting.

Treatment: Soil series	Soil-water tension (kPa)	Thiobencarb ($kg \cdot ha^{-1}$) 0	4	8	Signif.[z]
		Barnyardgrass dry wt ($mg \cdot flat^{-1}$)			
Pahokee muck					
	10	220	101	98	L**
	100	241	134	33	L**
Signif.	NS	NS	NS		
Everglades muck					
	10	527	164	68	Q**
	100	289	109	70	L**
Signif.	**	NS	NS		
Immokalee sand					
	10	207	0	0	Q*
	100	309	3	2	Q**
Signif.	NS	NS	NS		

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

decreased from 527 to 164 mg as thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$, and decreased from 164 to 68 mg with an increase from 4 to 8 $kg \cdot ha^{-1}$ thiobencarb. On the Everglades muck soil at 100 kPa soil-water tension, barnyardgrass dry weights decreased from 289 to 70 mg as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. On the Immokalee sand, barnyardgrass dry weights decreased from 207 to 0 mg and 309 to 3 mg as thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$ at 10 and 100 kPa soil-water tension, respectively.

Protectant study

Data on the main effects of protectants on thiobencarb injury to lettuce are shown in Table 3.18. The application of seed protectants had no effect on lettuce vigor, plant stand, or dry weight. Lettuce vigor, stand, and dry weight decreased with the application of 8 $kg \cdot ha^{-1}$ of thiobencarb. Lettuce vigor ratings and dry weights were higher when grown on the Everglades muck than the Pahokee muck while lettuce stands were similar. Vigor and stand of lettuce grown on the muck soils were higher than those on the Immokalee sand.

Thiobencarb rate and soil series interacted in their effects on lettuce vigor and stand (Table 3.19). Butterhead lettuce vigor, butterhead lettuce stand, and crisphead lettuce stand with no thiobencarb were similar on the three soils, but those parameters were greater on the

Table 3.18. Main effect of protectants on thiobencarb injury to lettuce in three soils in greenhouse studies at 21 days after planting.

Treatment	Butterhead lettuce Vigor (%)	Butterhead lettuce Stand (no.·flat^{-1})	Butterhead lettuce Dry weight (mg·flat^{-1})	Crisphead lettuce Vigor (%)	Crisphead lettuce Stand (no.·flat^{-1})	Crisphead lettuce Dry weight (mg·flat^{-1})
Protectant (P)						
None	71	8.8	327	72	8.5	322
Activated charcoal	72	8.0	324	70	8.5	313
Naphthalic anhydride	68	9.5	318	70	8.0	301
Signif.[z]	NS	NS	NS	NS	NS	NS
Thiobencarb (kg·ha^{-1}) (T)						
0	100	10.5	372	100	10.1	384
8	46	7.1	270	47	6.6	228
Signif.	**	**	**	**	**	**
Soil series (S)						
Pahokee muck (1)	66	9.8	185	69	9.7	207
Everglades muck (2)	87	10.0	499	87	10.0	476
Immokalee sand	57	6.5	307	55	5.3	271
Contrast[y]						
Muck 1 vs 2	**	NS	**	**	NS	**
Muck 1 + 2 vs sand	**	**	NS	**	**	*
Interactions						
T × S	**	**	NS	**	**	NS
T × P	NS	NS	NS	NS	NS	*

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).
[y]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

Table 3.19. Interaction of thiobencarb and soil series on lettuce vigor and stand in greenhouse studies at 21 days after planting.

Thiobencarb ($kg \cdot ha^{-1}$)	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
	Butterhead lettuce vigor (%)				
0	89	100	93	**	NS
8	43	75	20	**	**
Signif.[y]	**	**	**		
	Butterhead lettuce (pelleted) stand ($no. \cdot flat^{-1}$)				
0	11	11	10	NS	NS
8	9	10	3	NS	**
Signif.	NS	NS	**		
	Crisphead lettuce vigor (%)				
0	90	98	94	NS	NS
8	48	76	16	**	**
Signif.	**	**	**		
	Crisphead lettuce (pelleted) stand ($no. \cdot flat^{-1}$)				
0	11	11	9	NS	**
8	9	9	2	NS	**
Signif.	*	*	**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).

muck soils than the Immokalee sand with 8 $kg \cdot ha^{-1}$ of thiobencarb. Crisphead lettuce stands were similar on the Pahokee and Everglades mucks and were greater on the muck soils than on the Immokalee sand.

Thiobencarb rate interacted with protectants on crisphead lettuce dry weight data (Table 3.20). The dry weights of crisphead lettuce plants grown from untreated seed, or seed treated with naphthalic anhydride, decreased as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. With the application of activated charcoal, crisphead lettuce dry weights were similar with 0 or 8 $kg \cdot ha^{-1}$ thiobencarb.

Irrigation study

The main effects of irrigation method, thiobencarb rate, and soil series on lettuce and weed plant stand data are shown in Table 3.21. Butterhead lettuce stands were similar with the subsurface and overhead irrigation treatments but the mean stands of subsurface and overhead irrigation were less than with the overhead + subsurface treatment combination. Crisphead lettuce, barnyardgrass, and purslane stands were not affected by irrigation method.

Butterhead lettuce, barnyardgrass, and purslane stands decreased sharply with an increase in thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ but were similar with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb. Crisphead lettuce stands decreased

Table 3.20. Interaction of thiobencarb and protectants on crisphead lettuce dry weight in greenhouse studies at 21 days after planting.

Protectant	Thiobencarb ($kg \cdot ha^{-1}$) 0	8	Signif.[z]
	Crisphead lettuce dry wt ($mg \cdot flat^{-1}$)		
None	443	190	**
Activated charcoal (C)	348	274	NS
Naphthalic anhydride (N)	362	218	**
Contrast[y]			
None vs C + N	*	NS	
C vs N	NS	NS	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS).

[y]Differences between no protectant and charcoal (C) + naphthalic anhydride (N) were significant at the 5% (*) level or nonsignificant (NS); differences between charcoal (C) and naphthalic anhydride (N) were nonsignificant (NS) by orthogonal comparison.

Table 3.21. Main effect of irrigation method, thiobencarb rate, and soil series on lettuce and weed stand in greenhouse studies at 21 days after planting.

Treatment	Lettuce (no.•flat^{-1})		Weeds (no.•flat^{-1})	
	Butterhead	Crisphead	Barnyardgrass	Purslane
Irrigation method (I)				
Subsurface (1)	7	6	9	6
Overhead + subsurface (2)	8	6	10	5
Overhead (3)	6	6	10	7
Contrast^{z}				
Irrig. 1 vs 3	NS	NS	NS	NS
Irrig. 1 + 3 vs 2	**	NS	NS	NS
Thiobencarb rate (kg•ha^{-1}) (T)				
0	9	9	12	10
4	6	6	8	4
8	6	4	8	3
Signif.^{y}	Q**	L**	Q**	Q**
Soil (S)				
Pahokee muck (1)	6	5	12	5
Everglades muck (2)	8	8	11	9
Immokalee sand	7	5	6	4
Contrast^{x}				
Muck 1 vs 2	**	**	NS	**
Muck 1 + 2 vs sand	NS	**	**	**
Interactions				
I × S	**	**	*	NS
T × S	NS	*	**	**

Table 3.21--continued.

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.
[y]F tests were significant at the 1% (**) level and were linear (L) or quadratic (Q).
[x]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

from 9 to 4 plants·flat^{-1} as thiobencarb rate increased from 0 to 8 kg·ha^{-1}. Butterhead lettuce, crisphead lettuce, and purslane stands were greater on the Everglades muck than on the Pahokee muck while barnyardgrass stands were similar. The mean crisphead lettuce, barnyardgrass, and purslane stands on the muck soils were greater than on the Immokalee sand. The butterhead lettuce stands on the mucks were similar to those grown on the sand.

Irrigation method and soil series interacted in their effects on butterhead lettuce, crisphead lettuce, and barnyardgrass stand (Table 3.22). Butterhead lettuce stands on the Pahokee muck were greater with overhead irrigation than subsurface irrigation but the mean stand with the subsurface and overhead irrigated treatments were similar to that with the overhead + subsurface treatment. Crisphead lettuce stands on the Pahokee muck were greater with overhead irrigation than with subsurface irrigation, but barnyardgrass was not affected by irrigation on the Pahokee muck. Butterhead, crisphead lettuce, and barnyardgrass stands on the Everglades muck were not affected by irrigation method. Butterhead lettuce stands on the Immokalee sand were greater with subsurface than with overhead irrigation and the mean stand with the subsurface and overhead irrigated treatments was lower than with the overhead + subsurface treatment. On the Immokalee sand, butterhead, crisphead, and barnyardgrass stands were

Table 3.22. Interaction of irrigation method and soil series on plant stand in the greenhouse studies at 21 days after planting.

Irrigation method	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
	Butterhead lettuce (no.·flat^{-1})				
Subsurface (1)	5	8	8	**	NS
Overhead + subsurface (2)	6	8	9	*	*
Overhead (3)	7	8	3	NS	**
Irrig. 1 vs 3[y]	**	NS	**		
Irrig. 1 + 3 vs 2	NS	NS	**		
	Crisphead lettuce (no.·flat^{-1})				
Subsurface (1)	5	7	7	*	NS
Overhead + subsurface (2)	5	7	6	*	NS
Overhead (3)	7	8	2	NS	**
Irrig. 1 vs 3	*	NS	**		
Irrig. 1 + 3 vs 2	**	NS	*		
	Barnyardgrass (no.·flat^{-1})				
Subsurface (1)	11	11	6	NS	**
Overhead + subsurface (2)	13	11	6	NS	**
Overhead (3)	13	12	4	NS	**
Irrig. 1 vs 3	NS	NS	**		
Irrig. 1 + 3 vs 2	NS	NS	NS		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (**) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

[y]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

greater with subsurface than overhead irrigation. Barnyardgrass stands on the Immokalee sand with the mean of the subsurface and overhead irrigated treatments were similar to that with the overhead + subsurface treatment. The butterhead lettuce, crisphead lettuce, and barnyardgrass stands were lower on the Immokalee sand with overhead irrigation than with the other irrigation and soil treatment combinations.

Thiobencarb rate and soil series interacted in their effects on plant stand (Table 3.23). Crisphead lettuce, barnyardgrass, and purslane stands on the Pahokee muck decreased linearly as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. On the Everglades muck, crisphead lettuce stands decreased from 10 to 5 $plants \cdot flat^{-1}$ as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$ but barnyardgrass and purslane stands were not affected by thiobencarb rate. On the Immokalee sand, crisphead lettuce, barnyardgrass, and purslane stands on the Immokalee sand decreased sharply with an increase in thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ and decreased slightly more with an increase from 4 to 8 $kg \cdot ha^{-1}$ thiobencarb.

The main effects of irrigation method, thiobencarb rate and soil series on lettuce vigor and weed control data are shown in Table 3.24. Lettuce vigor and weed control ratings were not affected by irrigation method. Lettuce vigor decreased sharply and weed control increased sharply

Table 3.23. Interaction of thiobencarb rate and soil series on plant stand in greenhouse studies at 21 days after planting.

Thiobencarb ($kg \cdot ha^{-1}$)	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
	Crisphead lettuce ($no. \cdot flat^{-1}$)				
0	8	10	9	*	NS
4	5	8	4	**	**
8	4	5	2	NS	**
Signif.[y]	L**	L**	Q**		
	Barnyardgrass ($no. \cdot flat^{-1}$)				
0	13	11	12	*	NS
4	12	11	2	NS	**
8	11	11	1	NS	**
Signif.	L*	NS	Q**		
	Purslane ($no. \cdot flat^{-1}$)				
0	10	10	11	NS	NS
4	4	8	1	*	**
8	2	8	1	**	**
Signif.	L*	NS	Q**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

Table 3.24. Main effect of irrigation method, thiobencarb rate, and soil series on visual ratings of lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Treatment	Lettuce vigor (%)		Weed control (%)	
	Butterhead	Crisphead	Barnyardgrass	Purslane
Irrigation method (I)				
Subsurface (1)	50	48	60	64
Overhead + subsurface (2)	48	51	60	61
Overhead (3)	48	50	59	59
Contrast^{z}				
Irrig. 1 vs 3	NS	NS	NS	NS
Irrig. 1 + 3 vs 2	NS	NS	NS	NS
Thiobencarb rate ($kg \cdot ha^{-1}$) (T)				
0	100	100	0	0
4	36	41	80	80
8	21	20	91	89
Signif.^{y}	Q**	Q**	Q**	Q**
Soil series (S)				
Pahokee muck (1)	53	53	54	60
Everglades muck (2)	56	62	56	53
Immokalee sand	37	34	70	72
Contrast^{x}				
Muck 1 vs 2	NS	**	NS	*
Muck 1 + 2 vs sand	**	**	**	**
Interactions				
I × S	NS	**	NS	NS
T × S	**	**	**	**

Table 3.24--continued.

^{z}Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

^{y}F tests were significant at the 1% (**) level and were quadratic (Q).

^{x}Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level by orthogonal comparison.

with an increase in the thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ and these responses increased slightly more with a further increase in thiobencarb to 8 $kg \cdot ha^{-1}$. Butterhead lettuce vigor and barnyardgrass control were not affected by the type of muck soil they were grown on. Lettuce vigor was greater and weed control was lower on the muck soils than on the Immokalee sand.

Irrigation and soil series, and thiobencarb rate and soil series interacted in their effects on lettuce vigor and weed control (Table 3.25). Crisphead lettuce vigor ratings on the Pahokee muck were similar with all irrigation methods. Crisphead lettuce vigor ratings were greater on the Everglades muck and lower on the Immokalee sand, with the application of overhead than subsurface irrigation. Butterhead lettuce vigor, crisphead lettuce vigor, barnyardgrass control, and purslane control were not affected by soil series in the untreated check. With the application of 8 $kg \cdot ha^{-1}$ of thiobencarb, butterhead lettuce vigor ratings were greater on the Everglades muck than the Pahokee muck. Barnyardgrass control ratings were greater on the Pahokee with 4 and Everglades muck soil with 8 $kg \cdot ha^{-1}$ of thiobencarb, respectively. Purslane control ratings were greater on the Pahokee muck than on the Everglades muck. Lettuce vigor ratings were lower and weed control ratings were greater on the Immokalee sand than on

Table 3.25. Interaction of irrigation method and soil series, and between thiobencarb rate and soil series on lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Treatment	Soil series: Pahokee muck (1)	Soil series: Everglades muck (2)	Soil series: Immokalee sand	Contrast[z]: Muck 1 vs 2	Contrast[z]: Muck 1 + 2 vs sand
Irrigation method					
	Crisphead lettuce vigor (%)				
Subsurface (1)	50	56	39	*	**
Overhead + subsurface (2)	55	60	36	NS	**
Overhead (3)	53	70	29	**	**
Contrast[y]					
Irrig. 1 vs 3	NS	**	*		
Irrig. 1 + 3 vs 2	NS	NS	NS		
Thiobencarb ($kg \cdot ha^{-1}$)					
	Butterhead lettuce vigor (%)				
0	100	100	100	NS	NS
4	47	48	13	NS	**
8	25	30	8	*	**
Signif.[x]	Q**	Q**	Q**		
	Crisphead lettuce vigor (%)				
0	100	100	100	NS	NS
4	49	63	11	**	**
8	21	34	4	**	**
Signif.	Q**	L**	Q**		
	Barnyardgrass control (%)				
0	0	0	0	NS	NS
4	64	74	99	**	**
8	89	84	100	**	**
Signif.	Q**	Q**	Q**		

Table 3.25--continued.

Treatment	Soil series			Contrast[z]	
	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
	Purslane control (%)				
0	0	0	0	NS	NS
4	77	65	98	*	**
8	94	72	99	**	**
Signif.	Q**	Q**	Q**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were nonsignificant (NS) by orthogonal comparison.

[x]F tests were significant at the 1% (**) level, and were linear (L) or quadratic (Q).

the muck soils with 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb than with no thiobencarb.

The main effect of irrigation method, thiobencarb rate, and soil series on plant stand, lettuce vigor, weed control, and plant dry weight data are shown in Table 3.26. Butterhead and crisphead lettuce dry weights were greater with subsurface than overhead irrigation, purslane dry weights were greater with overhead irrigation, and barnyardgrass dry weights were similar with subsurface and overhead irrigation. The mean of the overhead and subsurface irrigation treatments were similar to the overhead + subsurface irrigation treatment in their effect on lettuce and weed plant dry weights. Lettuce and weed dry weights were reduced sharply with an increase in thiobencarb rate from 0 to 4 $kg \cdot ha^{-1}$ and decreased slightly with an increase to 8 $kg \cdot ha^{-1}$ thiobencarb. Butterhead lettuce, crisphead lettuce, and barnyardgrass dry weights were greater on the Everglades muck than the Pahokee muck and purslane weights were similar on all soils. Butterhead lettuce dry weights were similar on the mean of the muck soils and the Immokalee sand, but the dry weights of crisphead lettuce and barnyardgrass on the mean of the muck soils were greater than on the Immokalee sand.

Irrigation method and thiobencarb rate, and irrigation and soil series interacted in their effects on butterhead and crisphead lettuce dry weight, respectively (Table 3.27). Butterhead lettuce dry weights were greater with

Table 3.26. Main effect of irrigation method, thiobencarb rate, and soil series on lettuce and weed dry weight in greenhouse studies at 21 days after planting.

Treatment	Lettuce dry wt ($mg \cdot flat^{-1}$)		Weed dry wt ($mg \cdot flat^{-1}$)	
	Butterhead	Crisphead	Barnyardgrass	Purslane
Irrigation method (I)				
Subsurface (1)	193	170	172	39
Overhead + subsurface (2)	175	166	162	39
Overhead (3)	117	117	190	59
Contrast[z]				
Irrig. 1 vs 3	**	*	NS	*
Irrig. 1 + 3 vs 2	NS	NS	NS	NS
Thiobencarb rate ($kg \cdot ha^{-1}$) (T)				
0	250	274	390	95
4	138	113	86	25
8	97	65	48	17
Signif.[y]	Q*	Q**	Q**	Q**
Soil series (S)				
Pahokee muck (1)	96	98	181	43
Everglades muck (2)	243	236	228	57
Immokalee sand	146	118	115	37
Contrast[x]				
Muck 1 vs 2	**	**	**	NS
Muck 1 + 2 vs sand	NS	**	**	NS
Interactions				
I × T	NS	**	NS	NS
I × S	*	NS	**	NS
T × S	*	NS	*	**
I × T × S	NS	NS	**	NS

Table 3.26--continued.

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level, and were quadratic (Q).

[x]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

Table 3.27. Interaction of irrigation method and thiobencarb rate, and irrigation method and soil series on lettuce dry weight in greenhouse studies at 21 days after planting.

Treatment	Irrigation method: Subsurface (1)	Overhead + Subsurface (2)	Overhead (3)	Contrast[z]: Irrig. 1 vs 3	Irrig. 1 + 3 vs 2
Thiobencarb ($kg \cdot ha^{-1}$)	Butterhead lettuce dry wt ($mg \cdot flat^{-1}$)				
0	298	266	186	**	NS
4	180	151	82	**	NS
8	100	109	83	NS	NS
Signif.[y]	L**	L**	L**		
Soil series	Crisphead lettuce dry wt ($mg \cdot flat^{-1}$)				
Pahokee muck (1)	84	113	96	NS	NS
Everglades muck (2)	264	229	216	NS	NS
Immokalee sand	163	156	36	**	*
Contrasts[x]					
Muck 1 vs 2	**	**	**		
Muck 1 + 2 vs sand	NS	NS	**		

[z] Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) or nonsignificant (NS) by orthogonal comparison.

[y] F tests were significant at the 1% (**) level and were linear (L).

[x] Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level; differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

subsurface than overhead irrigation with 0 or 4 $kg{\cdot}ha^{-1}$ of thiobencarb, but were not affected by irrigation method with 8 $kg{\cdot}ha^{-1}$ of thiobencarb. Crisphead lettuce dry weights on the Pahokee and Everglades muck were not affected by irrigation method. On the Immokalee sand the crisphead lettuce dry weights were much greater with subsurface than overhead irrigation.

Thiobencarb rate and soil series interacted in their effects on butterhead lettuce and purslane dry weight (Table 3.28). Butterhead lettuce dry weight on the Pahokee and Everglades mucks decreased sharply with an increase in thiobencarb rate from 0 to 4 $kg{\cdot}ha^{-1}$ and were similar with a further increase to 8 $kg{\cdot}ha^{-1}$. Purslane dry weights on the Pahokee muck and Immokalee sand decreased very sharply with an increase from 0 to 4 $kg{\cdot}ha^{-1}$ thiobencarb, but on the Everglades muck, purslane dry weight decreased linearly from 76 to 44 mg as thiobencarb increased from 0 to 8 $kg{\cdot}ha^{-1}$.

Irrigation method, thiobencarb rate, and soil series interacted in their effects on barnyardgrass dry weight (Table 3.29). Barnyardgrass dry weights on the Pahokee muck with no thiobencarb were greater with subsurface than overhead irrigation and the mean dry weights with the subsurface and overhead irrigated treatments were greater than with overhead + subsurface treatment. With an

Table 3.28. Interaction of thiobencarb rate and soil series on plant dry weight in greenhouse studies at 21 days after planting.

Thiobencarb ($kg \cdot ha^{-1}$)	Soil series			Contrast[z]	
	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
	Butterhead lettuce dry wt ($mg \cdot flat^{-1}$)				
0	157	370	223	**	NS
4	62	206	146	**	NS
8	68	152	71	**	NS
Signif.[y]	Q**	Q**	L**		
	Purslane dry wt ($mg \cdot flat^{-1}$)				
0	106	76	105	NS	NS
4	18	52	4	*	*
8	6	44	1	*	NS
Signif.	Q**	L*	Q**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level, and were linear (L) or quadratic (Q).

Table 3.29. Interaction of irrigation method, thiobencarb rate, and soil series on barnyardgrass dry weight in greenhouse studies at 21 days after planting.

	Barnyardgrass dry wt ($mg \cdot flat^{-1}$)				
	Irrigation method			Contrast[z]	
Thiobencarb ($kg \cdot ha^{-1}$)	Subsurface (1)	Overhead + Subsurface (2)	Overhead (3)	Irrig. 1 vs 3	Irrig. 1 + 3 vs 2
		Pahokee muck			
0	472	244	353	*	**
4	141	118	124	NS	NS
8	57	57	67	NS	NS
Signif.[y]	Q**	L**	L**		
		Everglades muck			
0	355	452	616	**	NS
4	93	114	184	NS	NS
8	67	119	57	NS	NS
Signif.	Q**	Q**	Q**		
		Immokalee sand			
0	354	353	315	NS	NS
4	0	3	0	NS	NS
8	6	0	0	NS	NS
Signif.	Q**	Q**	Q**		

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were signifioant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 1% (**) level, and were linear (L) or quadratic (Q).

application of 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb on the Pahokee muck, barnyardgrass dry weights decreased and were not affected by irrigation method. On the Everglades muck with no thiobencarb, barnyardgrass dry weights were greater with overhead than subsurface irrigation. With 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb, barnyardgrass dry weights were not affected by irrigation method. With all irrigation methods on the Immokalee sand, barnyardgrass dry weights decreased sharply as thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$ and were not decreased with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb.

Thiobencarb placement and irrigation method study

The effects of irrigation method, thiobencarb rate, placement method, and soil series on lettuce and weed stand data are shown in Table 3.30. Lettuce stands were greater with subsurface than overhead irrigation, but the mean stand with the subsurface and overhead irrigated treatments was similar to that stand with the overhead + subsurface treatment. Barnyardgrass and purslane stands were not affected by irrigation method. Lettuce, barnyardgrass, and purslane stands were greater with 0 than 8 $kg \cdot ha^{-1}$ of thiobencarb.

Lettuce stands were not affected by thiobencarb placement method, but barnyardgrass and purslane stands were greater with thiobencarb applied preemergence (PRE)

Table 3.30. Main effect of irrigation method, thiobencarb rate, placement method, and soil series on lettuce and weed stands in greenhouse studies at 21 days after planting.

Treatment	Plants (no.·pot^{-1})		
	Lettuce	Barnyard grass	Purslane
Irrigation method (I)			
Subsurface (1)	9	9	6
Overhead + Subsurface (2)	7	9	6
Overhead (3)	7	9	6
Contrast[z]			
1 vs 3	*	NS	NS
1 + 3 vs 2	NS	NS	NS
Thiobencarb (kg·ha^{-1}) (T)			
0	10	13	9
8	5	5	2
Signif.[y]	**	**	**
Placement (P)			
PRE[x]	8	10	7
PPI	8	8	4
Signif.	NS	**	**
Soil series (S)			
Pahokee muck (1)	7	10	5
Everglades muck (2)	10	10	6
Immokalee sand	7	7	5
Contrast[w]			
Muck 1 vs 2	**	NS	NS
Muck 1 + 2 vs sand	*	**	NS
Interactions			
I × T	**	NS	NS
T × P	**	**	**
T × S	**	**	**
I × T × S	NS	*	*
I × P × S	NS	NS	**
T × P × S	NS	**	**
I × T × P × S	NS	*	NS

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of

Table 3.30--continued.

subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 1% (**) level or nonsignificant (NS).

[x]Preemergence (PRE) and preplant incorporated (PPI).

[w]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

than preplant incorporated (PPI). Lettuce stands were greater on the Everglades muck than the Pahokee muck and the mean lettuce stand on the muck soils was greater than that on the Immokalee sand. Barnyardgrass stands were similar on the Pahokee and Everglades muck, and the mean lettuce stand on the muck soils was greater than that on the Immokalee sand. Purslane stands were similar on all soils.

Thiobencarb rate and irrigation method, thiobencarb rate and placement method, and thiobencarb rate and soil series interacted in their effects on lettuce stand (Table 3.31). Lettuce stands were greater with 0 than 8 $kg{\cdot}ha^{-1}$ thiobencarb with subsurface or overhead irrigations. Lettuce stands were not affected by thiobencarb rate with the overhead + subsurface irrigation method. Lettuce stands were greater with the PRE than PPI (disturbed soil surface) in the untreated checks, but were greater with the PPI than PRE application of 8 $kg{\cdot}ha^{-1}$ thiobencarb. Lettuce stands on the Pahokee muck and Immokalee sand were greater with 0 than 8 $kg{\cdot}ha^{-1}$ thiobencarb, but on the Everglades muck thiobencarb rate had no effect on lettuce stand. Lettuce stands were reduced more on the Immokalee sand with 8 $kg{\cdot}ha^{-1}$ of thiobencarb than on other soil.

Irrigation method, thiobencarb rate, placement method, and soil series interacted in their effects on

Table 3.31. Interaction of thiobencarb rate and irrigation method, thiobencarb rate and placement, and thiobencarb rate, and soil series on lettuce stand in greenhouse studies at 21 days after planting.

Treatment	Thiobencarb ($kg \cdot ha^{-1}$) 0	8	Signif.[z]
	Lettuce ($no \cdot pot^{-1}$)		
Irrigation method			
Subsurface (1)	12	6	**
Overhead + subsurface (2)	8	6	NS
Overhead (3)	11	4	**
Contrast[y]			
Irrig. 1 vs 3	NS	NS	
Irrig. 1 + 3 vs 2	NS	NS	
Placement			
PRE[x]	11	4	**
PPI	9	7	**
Signif.	*	**	
Soil series			
Pahokee muck (1)	8	5	**
Everglades muck (2)	10	10	NS
Immokalee sand	12	1	**
Contrast[w]			
Muck 1 vs 2	NS	**	
Muck 1 + 2 vs sand	**	**	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS).

[y]Differences between subsurface irrigation (1) and overhead irrigation (3) were nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were nonsignificant (NS) by orthogonal comparison.

[x]Preemergence (PRE) and preplant incorporated (PPI).

[w]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level by orthogonal comparison.

barnyardgrass stand (Table 3.32). Irrigation method, soil series and placement method did not affect barnyardgrass stands with no thiobencarb. With 8 kg·ha^{-1} thiobencarb, barnyardgrass stands decreased more with the PRE than PPI applications on the Pahokee and Everglades muck. With 8 kg·ha^{-1} thiobencarb on the Immokalee sand, barnyardgrass stands were lower than with no thiobencarb, with all placement and irrigation methods.

Irrigation method, thiobencarb rate, and soil series interacted in their effects on purslane stand (Table 3.33). Purslane stands were greater on the Everglades muck than on the Pahokee muck with no thiobencarb and with subsurface irrigation, but were similar on the muck soils with overhead + subsurface or overhead irrigation. With an 8 kg·ha^{-1} application of thiobencarb, purslane stands were similar on the muck soils with subsurface or overhead irrigation, but were significantly greater on the Pahokee than Everglades muck with the overhead + subsurface irrigation treatment. With an 8 kg·ha^{-1} application of thiobencarb, purslane stands were greater on the muck soils than the sand with subsurface or overhead irrigation, but were similar on the mucks and sand with overhead + subsurface irrigation.

Irrigation method, thiobencarb placement method, and soil series interacted in their effects on purslane stand

Table 3.32. Interaction of irrigation method, thiobencarb rate, placement, and soil series on barnyardgrass stand in greenhouse studies at 21 days after planting.

		Irrigation								
		Subsurface			Overhead + Subsurface			Overhead		
		Thiobencarb ($kg \cdot ha^{-1}$)								
Soil series	Placement	0	8	Signif.[z]	0	8	Signif.	0	8	Signif.
		Barnyardgrass ($no. \cdot pot^{-1}$)								
Pahokee muck	PRE[y]	14	6	**	15	0	**	12	0	**
	PPI	13	11	NS	13	12	NS	11	11	NS
Signif.		NS	**		NS	**		NS	**	
Everglades muck	PRE	14	1	**	13	5	**	13	1	**
	PPI	12	12	NS	11	11	NS	14	9	**
Signif.		NS	**		NS	**		NS	**	
Immokalee sand	PRE	14	0	**	13	0	**	16	0	**
	PPI	14	1	**	13	0	**	14	1	**
Signif.		NS	NS		NS	NS		NS	NS	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS).
[y]Preemergence (PRE) and preplant incorporated (PPI).

Table 3.33. Interaction of irrigation method, thiobencarb rate, and soil series on purslane stand in greenhouse studies at 21 days after planting.

Treatment		Soil series			Contrast[z]	
Irrigation	Thiobencarb	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
		Purslane (no ·pot^{-1})				
Subsurface						
	0	7	11	10	**	NS
	8	3	4	0	NS	**
Signif.[y]		**	**	**		
Overhead + Subsurface						
	0	8	10	8	NS	NS
	8	4	1	3	*	NS
Signif.		**	**	**		
Overhead						
	0	7	9	11	NS	*
	8	4	4	0	NS	**
Signif.		*	**	**		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 5% (*) or 1% (**) level.

(Table 3.34). Purslane stands were greater with a PPI than PRE application of thiobencarb on the Pahokee muck with overhead irrigation, on the Everglades muck with subsurface irrigation, and on the Immokalee sand with the overhead + subsurface irrigation. With other irrigation methods and soil series, purslane stands were not affected by thiobencarb placement.

Thiobencarb rate, placement method, and soil series also interacted in their effects on purslane stand (Table 3.35). Purslane stands with no thiobencarb were not affected by placement method. With 8 $kg \cdot ha^{-1}$ of thiobencarb, purslane stands were greater with PPI than PRE placement on the Pahokee and Everglades muck soils, but stands were similarly low with both placement methods on the Immokalee sand. Thiobencarb adsorption was probably higher with the PPI than PRE application method on the muck soils, and that resulted in higher lettuce stands. The adsorption of thiobencarb on the Immokalee sand was probably low with both methods of application, therefore lettuce stands were similarly low with PRE and PPI application methods.

The main effects of irrigation, thiobencarb rate, placement method, and soil series on lettuce vigor and weed control data are shown in Table 3.36. Lettuce vigor ratings were greater with subsurface than overhead irrigation. Barnyardgrass and purslane control ratings

Table 3.34. Interaction of irrigation method, thiobencarb placement method, and soil series on purslane stand in greenhouse studies at 21 days after planting.

Treatment		Soil series			Contrast[z]	
Irrigation	Placement	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
		Purslane (no $\cdot pot^{-1}$)				
Subsurface						
	PRE[y]	4	4	5	NS	NS
	PPI	5	10	5	**	NS
Signif.[x]		NS	**	NS		
Overhead + Subsurface						
	PRE	5	6	4	NS	NS
	PPI	7	5	8	NS	NS
Signif.		NS	NS	**		
Overhead						
	PRE	3	4	4	NS	NS
	PPI	8	9	6	NS	NS
Signif.		**	**	NS		

[z] Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were nonsignificant (NS) by orthogonal comparison.

[y] Preemergence (PRE) and preplant incorporated (PPI).

[x] F tests were significant at the 1% (**) level or nonsignificant (NS).

Table 3.35. Interaction of thiobencarb rate, thiobencarb placement method, and soil series on purslane stand in greenhouse studies at 21 days after planting.

Treatment		Soil series			Contrast[z]	
Thiobencarb	Placement	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
		Purslane ($no.\cdot pot^{-1}$)				
0	PRE[y]	8	9	9	NS	NS
	PPI	6	11	10	**	NS
Signif.[x]		NS	NS	NS		
8	PRE	1	1	0	NS	NS
	PPI	7	6	2	NS	**
Signif.		**	**	NS		

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.
[y]Preemergence (PRE) and preplant incorporated (PPI).
[x]F tests were significant at the 1% (**) level or nonsignificant (NS).

Table 3.36. Main effect of irrigation method, thiobencarb rate, placement method, and soil series on lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Treatment	Lettuce vigor (%)	Weed control (%)	
		Barnyard-grass	Purslane
Irrigation method			
Subsurface (1)	70	44	46
Overhead + Subsurface (2)	66	43	44
Overhead (3)	67	42	43
Contrast[z]			
1 vs 3	**	NS	NS
1 + 3 vs 2	NS	NS	NS
Thiobencarb ($kg \cdot ha^{-1}$) (T)			
0	100	0	0
8	35	86	89
Signif.[y]	**	**	**
Placement (P)			
PRE[x]	58	47	49
PPI	77	40	40
Signif.	**	**	**
Soil series (S)			
Pahokee muck (1)	73	39	41
Everglades muck (2)	75	41	44
Immokalee sand	55	49	49
Contrast[w]			
Muck 1 vs 2	NS	NS	NS
Muck 1 + 2 vs sand	**	**	**
Interaction			
T × P × S	**	**	**

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were nonsignificant (NS) by orthogonal comparison.
[y]F tests were significant at the 1% (**) level.
[x]Preemergence (PRE) and preplant incorporated (PPI).

Table 3.36--continued.

[w]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level by orthogonal comparison.

were not affected by irrigation method. Lettuce vigor decreased, and barnyardgrass and purslane control increased as thiobencarb rate increased from 0 to 8 $kg{\cdot}ha^{-1}$. Lettuce vigor ratings were higher, and barnyardgrass and purslane control ratings were lower with thiobencarb applied PPI than PRE. Lettuce vigor, barnyardgrass control, and purslane control ratings were similar on the muck soils, but lettuce vigor ratings were less, and the barnyardgrass and purslane control ratings were greater on the Immokalee sand than the mean ratings with muck soils.

Thiobencarb rate, placement method, and soil series interacted in their effects on lettuce vigor, barnyardgrass control, and purslane control (Table 3.37). Lettuce vigor, and barnyardgrass and purslane control ratings were not affected by thiobencarb placement method in the untreated checks. With 8 $kg{\cdot}ha^{-1}$ thiobencarb on the Pahokee and Everglades muck, lettuce vigor ratings were higher (about 75%) and barnyardgrass and purslane control ratings were lower (about 24%) with thiobencarb applied PPI than PRE. On the Immokalee sand, lettuce vigor, barnyardgrass and purslane control ratings were greater than on the muck soils, but were not affected by placement method. Therefore, the PPI application on the muck soils increased the margin of selectivity (relative toxicity of thiobencarb to lettuce versus weeds) in favor of lettuce. The increase in the margin of selectivity with the PPI treatment may be

Table 3.37. Interaction of thiobencarb rate, placement method, and soil series on lettuce vigor and weed control in greenhouse studies at 21 days after planting.

Thiobencarb (kg·ha^{-1})	Placement method	Soil series			Contrast[z]	
		Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
		Lettuce vigor (%)				
0	PRE[y]	100	100	100	NS	NS
	PPI	100	100	100	NS	NS
Signif.[x]		NS	NS	NS		
8	PRE	12	24	10	**	*
	PPI	79	74	9	NS	**
Signif.		**	**	NS		
		Barnyardgrass control (%)				
0	PRE	0	0	0	NS	NS
	PPI	0	0	0	NS	NS
Signif.		NS	NS	NS		
8	PRE	92	89	100	NS	**
	PPI	66	77	96	**	**
Signif.		**	**	NS		
		Purslane control (%)				
0	PRE	0	0	0	NS	NS
	PPI	0	0	0	NS	NS
Signif.		NS	NS	NS		
8	PRE	98	98	100	NS	NS
	PPI	68	77	97	**	**
Signif.		**	**	NS		

Table 3.37--continued.

[z]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.
[y]Preemergence (PRE) and preplant incorporated (PPI).
[x]F tests were significant at the 1% (**) level or nonsignificant (NS).

due to differences in the metabolism of thiobencarb in the roots of lettuce and weeds (Reiners et al., 1988).

The main effects of irrigation, thiobencarb rate, placement method, and soil series on lettuce and weed dry weight data are shown in Table 3.38. Lettuce, barnyardgrass, and purslane dry weight ratings were greater with subsurface than overhead irrigation. Lettuce, barnyardgrass, and purslane dry weight ratings decreased with an increase in thiobencarb from 0 to 8 $kg \cdot ha^{-1}$, but were not affected by placement method. Lettuce dry weights were greater on the Everglades than Pahokee muck, but barnyardgrass and purslane dry weights were similar in both mucks. The mean lettuce and barnyardgrass dry weights were greater on the muck soils than the Immokalee sand, but purslane dry weights were similar on all soils.

Irrigation, thiobencarb rate, placement method, and soil series interacted in their effects on lettuce dry weight (Table 3.39). Lettuce dry weights on the Pahokee muck and Immokalee sand were not affected by irrigation or placement method, but on the Everglades muck were lower with the PPI than PRE application with no thiobencarb. Lettuce dry weights were greater on the muck soil with a PPI than a PRE application of 8 $kg \cdot ha^{-1}$ thiobencarb with subsurface irrigation, but were not affected by placement method with the other irrigation treatments.

Table 3.38. Main effect of irrigation method, thiobencarb rate, placement method, and soil series on lettuce and weed dry weight in greenhouse studies at 21 days after planting.

Treatment	Plant dry wt ($mg \cdot pot^{-1}$)		
	Lettuce	Barnyard-grass	Purslane
Irrigation method (I)			
Subsurface (1)	237	521	137
Overhead + Subsurface (2)	85	215	56
Overhead (3)	76	180	48
Contrast[z]			
1 vs 3	**	*	*
1 + 3 vs 2	*	NS	NS
Thiobencarb ($kg \cdot ha^{-1}$) (T)			
0	188	498	141
8	79	103	19
Signif.[y]	**	**	**
Placement (P)			
PRE[x]	117	333	75
PPI	151	276	85
Signif.	NS	NS	NS
Soil series (S)			
Pahokee muck (1)	118	362	79
Everglades muck (2)	188	431	77
Immokalee sand	96	125	85
Contrast[w]			
Muck 1 vs 2	**	NS	NS
Muck 1 + 2 vs sand	*	**	NS
Interactions			
I × T	**	**	**
I × S	**	**	NS
T × P	*	**	NS
T × S	**	NS	NS
I × P × S	NS	NS	*
T × P × S	*	*	NS
I × T × P × S	*	NS	NS

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level; differences between mean of subsurface (1) +

Table 3.38--continued.

overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) level or nonsignificant (NS) by orthogonal comparison.

[y]F tests were significant at the 1% (**) level.

[x]Preemergence (PRE) and preplant incorporated (PPI).

[w]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

Table 3.39. Interaction of irrigation method, thiobencarb rate, placement method, and soil series on lettuce dry weight in greenhouse studies at 21 days after planting.

		Irrigation method								
		Subsurface			Overhead + Subsurface			Overhead		
		Thiobencarb ($kg \cdot ha^{-1}$)								
Soil series	Placement	0	8	Signif.[z]	0	8	Signif.	0	8	Signif.
		Lettuce dry wt ($mg \cdot flat^{-1}$)								
Pahokee muck	PRE[y]	228	54	NS	66	26	NS	81	4	NS
	PPI	299	344	NS	139	59	NS	71	79	NS
Signif.		NS	**		NS	NS		NS	NS	
Everglades muck	PRE	710	76	**	139	49	NS	88	52	NS
	PPI	344	433	NS	22	171	NS	81	61	NS
Signif.		**	**		NS	NS		NS	NS	
Immokalee sand	PRE	139	11	NS	80	43	NS	218	0	*
	PPI	277	44	**	191	12	*	177	0	NS
Signif.		NS	NS		NS	NS		NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).
[y]Preemergence (PRE) and preplant incorporated (PPI).

Irrigation method and thiobencarb rate, and irrigation and soil series interacted in their effects on barnyard-grass dry weight (Table 3.40). Barnyardgrass dry weights with no thiobencarb were greater with subsurface than overhead irrigation. With 8 $kg \cdot ha^{-1}$ of thiobencarb, the barnyardgrass dry weights were lower in the untreated check with all irrigation methods. Barnyardgrass dry weights were similar on the two muck soils with all irrigation treatments, and on the sand except with subsurface irrigation where dry weights were lower than on the two muck soils.

Barnyardgrass dry weights were also affected by the interaction of thiobencarb rate, placement method and soil series (Table 3.41). With no thiobencarb, the barnyardgrass dry weights were greater PRE than PPI (disturbed soil surface) on the Pahokee and Everglades muck, but were not affected by placement method on the Immokalee sand. Barnyardgrass dry weights were lower with 8 $kg \cdot ha^{-1}$ thiobencarb applied PPI than PRE on the Pahokee muck, but were similarly low with 8 $kg \cdot ha^{-1}$ applied PRE or PPI on the Everglades muck and Immokalee sand.

The effects of irrigation and thiobencarb rate interacted on purslane dry weight (Table 3.42). Purslane dry weights with no thiobencarb were greater with subsurface than overhead + subsurface or overhead

Table 3.40. Interaction of irrigation method and thiobencarb rate, and irrigation method and soil series on barnyardgrass dry weight in greenhouse studies at 21 days after planting.

Treatment	Irrigation method: Subsurface (1)	Irrigation method: Overhead + Subsurface (2)	Irrigation method: Overhead (3)	Contrast[z]: Irrig. 1 vs 3	Contrast[z]: Irrig. 1 + 3 vs 2
	Barnyardgrass dry wt ($mg \cdot flat^{-1}$)				
Thiobencarb ($kg \cdot ha^{-1}$)					
0	873	308	311	**	**
8	147	117	49	NS	NS
Signif.[y]	**	*	**		
Soil series					
Pahokee muck (1)	744	188	186	**	**
Everglades muck (2)	687	360	239	**	NS
Immokalee sand	150	110	116	NS	NS
Contrast[x]					
Muck 1 vs 2	NS	NS	NS		
Muck 1 + 2 vs sand	**	NS	NS		

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.
[y]F tests were significant at the 5% (*) or 1% (**) level.
[x]Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

Table 3.41. Interaction of thiobencarb rate, placement, and soil series on barnyardgrass dry weight in greenhouse studies at 21 days after planting.

Treatment		Soil series			Contrast[z]	
Thiobencarb ($kg \cdot ha^{-1}$)	Placement	Pahokee muck (1)	Everglades muck (2)	Immokalee sand	Muck 1 vs 2	Muck 1 + 2 vs sand
		Barnyardgrass dry wt ($mg \cdot flat^{-1}$)				
0	PRE[y]	641	969	229	**	**
	PPI	395	486	267	NS	NS
Signif.[x]		*	**	NS		
8	PRE	50	47	0	NS	**
	PPI	326	179	5	NS	*
Signif.		*	NS	NS		

[z] Differences between Pahokee muck (muck 1) and Everglades muck (muck 2) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of Pahokee muck + Everglades muck and the Immokalee sand were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) by orthogonal comparison.

[y] Preemergence (PRE) and preplant incorporated (PPI).

[x] F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).

Table 3.42. Interaction of irrigation method and thiobencarb rate on purslane dry weight in greenhouse studies at 21 days after planting.

	Irrigation method			Contrast[z]	
Thiobencarb ($kg \cdot ha^{-1}$)	Subsurface (1)	Overhead + Subsurface (2)	Overhead (3)	Irrig. 1 vs 3	Irrig. 1 + 3 vs 2
	Purslane dry wt ($mg \cdot pot^{-1}$)				
0	245	88	87	**	**
8	24	23	11	NS	NS
Signif.[y]	**	NS	*		

[z] Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 1% (**) level or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 1% (**) level or nonsignificant (NS) by orthogonal comparison.

[y] F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).

irrigation, but were not affected by irrigation method with 8 kg·ha^{-1} thiobencarb.

Purslane dry weights were affected by an interaction between irrigation method, thiobencarb placement method, and soil series (Table 3.43). On the Pahokee muck and Immokalee sand, purslane dry weights were not affected by thiobencarb placement method with any irrigation method. On the Everglades muck, purslane dry weights were greater with the PPI than PRE thiobencarb placement method with subsurface irrigation but were not affected by placement method with overhead + subsurface or overhead irrigation.

The pelleted butterhead lettuce plant stands were generally lower than other lettuce types in the soil-water tension study, but butterhead, crisphead and pelleted crisphead lettuce plant stands were similar. Lettuce or weed plant stands generally decreased between 7 and 14 DAP, and were lower on the Immokalee sand than the Pahokee or Everglades muck soils. Kumiai (1977) found that barnyardgrass germinated but was killed by thiobencarb after emergence. With no thiobencarb there was no herbicide injury, but with 8 kg·ha^{-1}, the herbicide injury was severe and soil-water tension had no affect on lettuce plant stand. With 4 kg·ha^{-1} thiobencarb, water stress (with 100 kPa soil-water tension) aggravated the injury from thiobencarb, further reducing the lettuce plant stand. The stands of weeds were generally not affected by

Table 3.43. Interaction of irrigation method, placement, and soil series on purslane dry weight in greenhouse studies at 21 days after planting.

Treatment		Irrigation method			Contrast[z]	
Soil series	Placement	Subsurface (1)	Overhead + Subsurface (2)	Overhead (3)	Irrig. 1 vs 3	Irrig. 1 + 3 vs 2
		Purslane dry wt ($mg \cdot flat^{-1}$)				
Pahokee muck	PRE[y]	172	37	27	*	NS
	PPI	117	72	53	NS	NS
Signif.[x]		NS	NS	NS		
Everglades muck	PRE	67	61	73	NS	NS
	PPI	213	19	29	**	*
Signif.		*	NS	NS		
Immokalee sand	PRE	70	76	98	NS	NS
	PPI	182	70	17	**	NS
Signif.		NS	NS	NS		

[z]Differences between subsurface irrigation (1) and overhead irrigation (3) were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS); differences between mean of subsurface (1) + overhead irrigation (3) and overhead + subsurface irrigation (2) were significant at the 5% (*) level or nonsignificant (NS) by orthogonal comparison.
[y]Preemergence (PRE) and preplant incorporated (PPI).
[x]F tests were significant at the 5% (*) or nonsignificant (NS).

soil-water tension as much as lettuce. Barnyardgrass and purslane plant stand decreased as thiobencarb rate increased from 0 to 8 kg·ha^{-1}, but bermudagrass plant stand was not affected. Kumiai (1977) also found that purslane and barnyardgrass were more susceptible to thiobencarb than bermudagrass.

Lettuce vigor and weed control were affected more sharply by increasing the thiobencarb rate from 0 to 4 than 4 to 8 kg·ha^{-1}. Lettuce vigor ratings and dry weights were generally greater on the Everglades than Pahokee muck, and may have been due to higher fertility levels of the Everglades muck. Lettuce vigor ratings and dry weights were affected by drier conditions (100 than 10 kPa) more on the Everglades muck and Immokalee sand than on the Pahokee muck, and may be due to the retention of greater amounts of water and greater adsorption of thiobencarb on the Pahokee muck.

The activated charcoal (in the protectant study) may have adsorbed some thiobencarb (Chang and Mao, 1973) so the crisphead lettuce dry weights with 8 kg·ha^{-1} thiobencarb were similar those with the untreated check. However, activated charcoal had no effect on lettuce vigor or plant stand, that decreased with an increase in thiobencarb from 0 to 8 kg·ha^{-1}. Naphthalic anhydride has been shown to decrease thiobencarb injury to rice (Andrade, 1980) but did not affect thiobencarb injury to lettuce in this study.

The herbicidal activity of thiobencarb was generally greater with overhead than subsurface irrigation, but the increase in herbicidal activity also reduced lettuce vigor.

In the thiobencarb application method study, the uptake of thiobencarb may have been different in lettuce and weeds (relative importance of shoot versus root uptake) with PRE and PPI applications and increased margin of selectivity in favor of lettuce. Reiners et al. (1988) found that 'Dark-Green Boston' lettuce accumulated greater amount of thiobencarb in the leaves than the more tolerant 'Great Lakes 366' and the thiobencarb concentration affected leaves more than roots. Thiobencarb is not mobile in soil (Kumiai, 1977) but overhead irrigation may have desorbed some thiobencarb and increased phytotoxicity. In the Immokalee sand where thiobencarb adsorption was weaker than in the muck soils thiobencarb may have leached into the seed zone (Harris, 1966).

Field Studies

Thiobencarb application method and lettuce type tolerance to thiobencarb: Zellwood, Fall 1987

The main effect of thiobencarb rate and placement method in the fall on the vigor, number of heads and weight of butterhead, and crisphead lettuce data are shown in Table 3.44. Butterhead lettuce vigor ratings decreased from 100% to 70% with an increase in thiobencarb rate from

Table 3.44. Main effect of thiobencarb rate and placement method on lettuce vigor ratings and yield on an Everglades muck soil (Fall 1987).

	Lettuce type					
	Butterhead yield			Crisphead yield		
Treatment	Vigor (%)	Heads ($10^4 \cdot ha^{-1}$)	Weight ($MT \cdot ha^{-1}$)	Vigor (%)	Heads ($10^4 \cdot ha^{-1}$)	Weight ($MT \cdot ha^{-1}$)
Thiobencarb ($kg \cdot ha^{-1}$) (T)						
0	100	7.2	12.4	100	8.9	18.9
2	70[x]	8.1[x]	13.9[x]	79	8.0[w]	16.3[w]
4	47	7.9	10.1	67	8.5	16.8
8	32	7.0	8.5	42	7.3	9.8
Signif.[z]	Q**	C**	C**	L**	C**	C**
Placement (P)						
PRE[y]	47	7.5	9.9	50	7.9	14.1
PPI	77	7.6	12.6	94	8.4	16.8
Signif.	**	NS	**	**	NS	**
No herbicide						
Unhoed	100	7.2	12.4	100	8.9	18.9
Hoed	100	7.4	11.9	100	9.1	19.4
Signif.	NS	NS	NS	NS	NS	NS
Interaction						
T × P	*	NS	**	**	NS	**

Table 3.44--continued.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

[y]Preemergence (PRE) and preplant incorporated (PPI).

[x]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was linear.

[w]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was quadratic.

0 to 2 $kg \cdot ha^{-1}$. An increase in thiobencarb from 2 to 8 $kg \cdot ha^{-1}$ resulted in a linear decrease in vigor from 70 to 32%, respectively. Lettuce vigor ratings were significantly greater with preplant incorporated (PPI) applications of thiobencarb (77%) than with preemergence (PRE) (47%) applications. Application of thiobencarb resulted in injury to lettuce seedlings, reduced plant size, and new leaves did not unfold normally due to a fusion of the outer leaves. Other symptoms of thiobencarb phytotoxicity including twisting, cupping and strapping of the leaves. Since this study was conducted in the late fall, weed populations were very low and meaningful differences in weed control could not be established. Plant vigor, lettuce head number, and weight of both lettuce types were similar in the unhoed and hoed treatments. The soils in all the plots (except for the unhoed check) were hand hoed throughout the remainder of the experiment. This allowed for the comparison of the phytotoxic effect of thiobencarb treatments without the confounding effect of weed competition. Applications of thiobencarb at 2 to 8 $kg \cdot ha^{-1}$ resulted in a linear decrease from 8.1 to $7.0 \cdot 10^4 \cdot ha^{-1}$ heads and 13.9 to 8.5 $MT \cdot ha^{-1}$ of butterhead lettuce. The number of marketable butterhead lettuce heads produced were similar with the PRE and the PPI application of thiobencarb. Butterhead lettuce yields

were greater with 8 $kg \cdot ha^{-1}$ of thiobencarb applied PPI (12.6 $MT \cdot ha^{-1}$) than PRE (9.9 $MT \cdot ha^{-1}$).

Crisphead lettuce vigor ratings decreased from 100 to 42% with an increase in thiobencarb rate from 0 to 8 $kg \cdot ha^{-1}$. Crisphead lettuce vigor and head weight were significantly greater with thiobencarb applied PPI than PRE. The number of crisphead lettuce heads generally decreased with applications of thiobencarb between 2 to 8 $kg \cdot ha^{-1}$. With an increase in thiobencarb from 0 to 2 $kg \cdot ha^{-1}$, the number of heads decreased from 8.9 to $8.0 \cdot 10^4 \cdot ha^{-1}$. With a further increase in thiobencarb to 4 $kg \cdot ha^{-1}$, the number of heads increased from 8.0 to $8.5 \cdot 10^4$ $heads \cdot ha^{-1}$ but with an increase to 8 $kg \cdot ha^{-1}$ a sharp decrease to $7.3 \cdot 10^4$ $heads \cdot ha^{-1}$ occurred. The number of heads of crisphead lettuce produced was not affected by placement method. Crisphead lettuce yield decreased from 18.9 to 16.3 $MT \cdot ha^{-1}$ with an increase in thiobencarb applied from 0 to 2 $kg \cdot ha^{-1}$. The crisphead lettuce yields (16.3 and 16.8 $MT \cdot ha^{-1}$) were similar with 2 or 4 $kg \cdot ha^{-1}$ thiobencarb. With an increase to 8 $kg \cdot ha^{-1}$, there was a sharp decrease in crisphead lettuce yield to 9.8 $MT \cdot ha^{-1}$. Crisphead lettuce yields were significantly greater with thiobencarb applied as a PPI treatment (16.8 $MT \cdot ha^{-1}$) than as a PRE treatment (14.1 $MT \cdot ha^{-1}$).

Thiobencarb rate and placement method interacted in their effects on butterhead and crisphead lettuce vigor,

and head weights (Table 3.45). Butterhead lettuce vigor ratings decreased about 40% with each increase in thiobencarb rate from 0 to 2 and 2 to 4 kg$\cdot$ha^{-1}. A further increase in thiobencarb to 8 kg$\cdot$ha^{-1} resulted in an additional 9% decrease in butterhead lettuce vigor. With an increase in thiobencarb rate applied PPI, lettuce vigor decreased from 100 to 53%. With 0 to 4 kg$\cdot$ha^{-1} of thiobencarb, lettuce yields were similar among PRE and PPI treatments. With 8 kg$\cdot$ha^{-1} of thiobencarb applied PPI, there was a significantly greater butterhead lettuce yield (12.7 MT$\cdot$ha^{-1}) than when applied PRE (4.3 MT$\cdot$ha^{-1}).

Crisphead lettuce vigor ratings were similar with no thiobencarb , but with 2 to 8 kg$\cdot$ha^{-1} thiobencarb, vigor ratings were greater with thiobencarb applied PPI than PRE. Crisphead lettuce yields with 0 to 4 kg$\cdot$ha^{-1} of thiobencarb were similar with PRE and PPI applications. With 8 kg$\cdot$ha^{-1} thiobencarb, crisphead lettuce yields were greater with PPI (14.1 MT$\cdot$ha^{-1}) than PRE (5.5 MT$\cdot$ha^{-1}) applications.

Data from the study indicate the lack of weed competition resulted in similar lettuce yields with unhoed and hoed treatments. With the application of 4 kg$\cdot$ha^{-1} of thiobencarb applied PRE, or with 2, 4 or 8 kg$\cdot$ha^{-1} applied PPI, butterhead lettuce was more sensitive (lower % vigor) than crisphead lettuce. Lettuce vigor ratings at 3 weeks

Table 3.45. Interaction of thiobencarb rate and placement method on lettuce vigor and yield on an Everglades muck (Fall 1987).

Placement	Thiobencarb rate ($kg \cdot ha^{-1}$) 0	2	4	8	Signif.[z]
	Butterhead vigor (%)				
PRE[y]	100	60	19	10	Q**
PPI	100	80	75	53	L**
Signif.	NS	**	**	**	
	Butterhead yield ($MT \cdot ha^{-1}$)				
PRE	12.4	13.9	8.9	4.3	Q**
PPI	12.4	13.9	11.2	12.7	NS
Signif.	NS	NS	NS	**	
	Crisphead vigor (%)				
PRE	100	58	34	8	Q*
PPI	100	100	100	75	NS
Signif.	NS	**	**	**	
	Crisphead yield ($MT \cdot ha^{-1}$)				
PRE	18.9	14.8	17.0	5.5	C**
PPI	18.9	17.7	16.5	14.1	L**
Signif.	NS	NS	NS	**	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

[y]Preemergence (PRE) and preplant incorporated (PPI). At 0 kg thiobencarb the PRE and PPI values are from the same plot.

after planting were much lower with thiobencarb applied PRE versus PPI up to 4 $kg \cdot ha^{-1}$, but the lettuce yields were similar. Butterhead + crisphead lettuce vigor ratings were about 50% lower with 8 $kg \cdot ha^{-1}$ of thiobencarb applied PRE than PPI. These 50% losses of vigor were not outgrown and resulted in losses of about 8.5 $MT \cdot ha^{-1}$ with the PRE than PPI application of 8 $kg \cdot ha^{-1}$ thiobencarb.

Irrigation duration and thiobencarb application method study: Belle Glade, Fall 1987

The main effects of irrigation duration, thiobencarb rate, and placement method in the fall on lettuce vigor, weed control, and yield data are shown in Table 3.46. The duration of overhead irrigation had no effect on all weed or lettuce parameters. Lettuce vigor decreased from 100 to 72% and weed control increased from 0 to 40% as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$ applied PRE. The number of weeds decreased sharply from 18.4 to $10.7 \cdot 10^5 \cdot ha^{-1}$ as the thiobencarb rate increased from 0 to 4 $kg \cdot ha^{-1}$ of thiobencarb applied PRE. The number of weeds with 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb were similar with 10.7 and $10.6 \cdot 10^5$ $weeds \cdot ha^{-1}$, respectively. Weed dry weights decreased from 1147 $kg \cdot ha^{-1}$ with the unhoed check to 578 $kg \cdot ha^{-1}$ with 4 $kg \cdot ha^{-1}$ of thiobencarb. Weed dry weights (578 and 512 $kg \cdot ha^{-1}$) were similar with 4 or 8 $kg \cdot ha^{-1}$, respectively. Thiobencarb rate had no significant effect on the number of

Table 3.46. Main effect of irrigation duration, thiobencarb rate, and placement method on lettuce vigor, weed control and yield on a Pahokee muck (Fall 1987).

Treatment	Rating (%)		Weeds		Lettuce yield		
	Lettuce vigor	Weed control	Weed number ($10^5 \cdot ha^{-1}$)	Dry weight ($kg \cdot ha^{-1}$)	Marketable heads ($10^4 \cdot ha^{-1}$)	Percent marketable (%)	Weight ($MT \cdot ha^{-1}$)
Irrigation duration (da at 1.25 $cm \cdot da^{-1}$) (I)							
0	93	39	10.6	651	5.0	64	25.3
4	86	44	10.0	474	5.8	76	31.8
8	92	32	11.5	549	5.7	78	31.8
Signif.[z]	NS	NS	NS	NS	NS	NS	NS
Thiobencarb pre ($kg \cdot ha^{-1}$) (T)							
0	100	0	18.4	1147	5.5	72	23.6
4	85	30	10.7	578	5.4	73	29.3
8	72	40	10.6	512	4.9	67	26.9
Signif.	L**	L**	Q*	Q*	NS	NS	NS
Placement (8 $kg \cdot ha^{-1}$ thiobencarb) (P)							
PRE[y]	72	40	10.6	512	4.9	67	26.9
PPI	93	23	10.1	558	5.6	73	28.3
Signif.	**	**	NS	NS	NS	NS	NS
No Herbicide (Ck)							
Unhoed	100	0	18.4	1147	5.5	72	23.6
Hoed	100	100	4.0	28	5.7	79	39.9
Signif.	NS	**	**	**	NS	NS	**
Interactions							
I × T	NS	NS	NS	NS	*	*	NS
I × P	*	NS	NS	NS	*	NS	NS
I × Ck	NS	NS	NS	NS	NS	*	NS

Table 3.46--continued.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Preemergence (PRE) and preplant incorporated (PPI).

marketable lettuce heads, percentage of marketable heads, or yield.

Lettuce vigor ratings were 21% higher with a PPI than PRE application of 8 $kg \cdot ha^{-1}$ of thiobencarb. Weed control ratings were 17% lower with 8 $kg \cdot ha^{-1}$ of thiobencarb applied PPI than as PRE. Weed number, weight, and all components of yield were not affected by herbicide placement. The number and percentage of marketable lettuce heads were not affected by hoeing but lettuce yields were higher (39.9 $MT \cdot ha^{-1}$) with hoeing than without (23.6 $MT \cdot ha^{-1}$).

Irrigation duration and thiobencarb rate interacted in their effects on the number and percentage of marketable lettuce heads (Table 3.47). The number of marketable lettuce heads with no irrigation decrease linearly from 5.8 to $3.5 \cdot 10^4$ $heads \cdot ha^{-1}$ as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. With no irrigation, the percentage of marketable lettuce decreased linearly from 76 to 49% as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$. The number and percentage of marketable lettuce heads were not affected by thiobencarb rate with 4 or 8 days of overhead irrigation.

Irrigation duration and thiobencarb placement method interacted in their effects on lettuce vigor and the number of marketable heads (Table 3.48). With 8 $kg \cdot ha^{-1}$ thiobencarb applied PRE, lettuce vigor was not affected by irrigation duration but increased in response to irrigation duration with thiobencarb applied PPI. The effects of

Table 3.47. Interaction of irrigation duration and thiobencarb rate on the number and percentage of marketable heads of lettuce on a Pahokee muck (Fall 1987).

Thiobencarb ($kg \cdot ha^{-1}$)	Irrigation duration (da at 1.25 $cm \cdot da^{-1}$) 0	4	8	Signif.[z]
	Marketable heads ($10^4 \cdot ha^{-1}$)			
0	5.8	5.7	4.9	NS
4	5.3	5.6	5.4	NS
8	3.5	5.1	6.2	L**
Signif.	L**	NS	NS	
	Percent marketable (%)			
0	76	73	67	NS
4	66	72	81	NS
8	49	74	78	L*
Signif.	L*	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L).

Table 3.48. Interaction of irrigation duration and placement method on lettuce vigor and the number of marketable heads on a Pahokee muck (Fall 1987).

Placement ($8\ kg \cdot ha^{-1}$ thiobencarb)	Irrigation duration (da at $1.25\ cm \cdot da^{-1}$) 0	4	8	Signif.[z]
	Lettuce vigor (%)			
PRE[y]	83	63	70	NS
PPI	75	95	100	L**
Signif.	NS	**	**	
	Marketable heads ($10^4 \cdot ha^{-1}$)			
PRE	3.5	5.1	6.2	L**
PPI	5.7	5.6	5.6	NS
Signif.	*	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS).
[y]Preemergence (PRE) and preplant incorporated (PPI).

irrigation duration and placement method on the number of marketable heads were different than for lettuce vigor. The number of marketable heads increased linearly from 3.5 to $6.2 \cdot 10^4$ heads$\cdot$ha^{-1} as irrigation duration increased from 0 to 8 days with 8 kg$\cdot$ha^{-1} of thiobencarb applied PRE but irrigation duration had no affect with thiobencarb applied PPI.

Data on the interaction of irrigation and the unhoed and hoed checks on the percentage of marketable heads are presented in Table 3.49. The percentages of marketable lettuce heads were not affected by irrigation duration in the unhoed treatment but the percentage of marketable heads increased linearly from 55 to 89% with an increase in irrigation duration from 0 to 8 days.

Weed control increased and lettuce vigor decreased as thiobencarb rate increased, but the high level of weed competition resulted in lower lettuce yields than the hoed check at all rates of thiobencarb. In this study, the 8 kg$\cdot$ha^{-1} rate of thiobencarb significantly reduced weed number and weight by $7.8 \cdot 10^5 \cdot$ha^{-1} and 635 kg$\cdot$ha^{-1}, respectively over the unhoed check at 3 weeks after planting, but it did not provide the season long weed control needed to obtain the same lettuce yields as with hand cultivation. The early season weed control obtained

Table 3.49. Interaction of irrigation duration and herbicide-free treatments on the percentage of marketable heads in a Pahokee muck (Fall 1987).

Herbicide-free treatment	Irrigation duration (da at 1.25 $cm \cdot da^{-1}$)			
	0	4	8	Signif.[z]
	Marketable heads (%)			
Unhoed	76	73	67	NS
Hoed	55	92	89	L**
Signif.	NS	NS	NS	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS), and were linear (L).

at 3 weeks after planting with 4 and 8 $kg \cdot ha^{-1}$ thiobencarb helped reduce the labor needed to hoe lettuce and therefore, would reduce production costs.

Thiobencarb application method and lettuce type tolerance to thiobencarb: Zellwood, Spring 1988

The main effect of thiobencarb rate and placement method on weed control, lettuce vigor, and lettuce stand data are presented in Table 3.50. Weed control increased linearly from 0 to 65% with an increase in thiobencarb from 0 to 8 $kg \cdot ha^{-1}$. Butterhead and crisphead lettuce vigor decreased from 100 to 72% and from 100 to 67%, respectively, and butterhead lettuce stand increased from 6.3 to $7.8 \cdot 10^5$ $plants \cdot ha^{-1}$ as thiobencarb rates were increased from 0 to 8 $kg \cdot ha^{-1}$. Crisphead lettuce stands were not affected by thiobencarb rate. Weed control ratings were 10% lower and lettuce vigor ratings were about 25% higher with thiobencarb applied PPI than PRE. Butterhead and crisphead lettuce stands were not affected by herbicide placement method.

The vigor of butterhead and crisphead lettuce were affected by an interaction between thiobencarb rate and placement method (Table 3.51). Butterhead and crisphead lettuce vigor ratings decreased linearly from 100 to 47% and from 100 to 33%, respectively, as thiobencarb rate

Table 3.50. Main effect of thiobencarb rate and placement method on weed control, lettuce yield and stand on an Everglades muck (Spring 1988).

Treatment	Weed control (%)	Lettuce type: Butterhead Vigor (%)	Butterhead Stand ($10^5 \cdot ha^{-1}$)	Crisphead Vigor (%)	Crisphead Stand ($10^5 \cdot ha^{-1}$)
Thiobencarb ($kg \cdot ha^{-1}$) (T)					
0	0	100	6.3	100	6.4
2	33[y]	93	5.0	93	6.2
4	41	83	7.1	90	6.2
8	65	72	7.8	67	5.4
Signif.[z]	C**	L**	L**	L**	NS
Placement (P)					
PRE[x]	40	74	6.6	75	6.2
PPI	30	99	6.5	100	6.0
Signif.	**	**	NS	**	NS
No herbicide					
Unhoed	0	100	6.3	100	6.4
Hoed	100	100	5.0	100	6.2
Signif.	**	NS	NS	NS	NS
Interaction					
T × P	NS	**	NS	**	NS

[z]F tests were significant at the 1% (**) level or nonsignificant (NS) and were linear (L) or cubic (C).

[y]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was linear.

[x]Preemergence (PRE) and preplant incorporated (PPI). With no thiobencarb the PRE and PPI values are from the same plot.

Table 3.51. Interaction of thiobencarb rate and placement method on lettuce vigor on an Everglades muck (Spring 1988).

	Thiobencarb rate ($kg{\cdot}ha^{-1}$)				
Placement	0	2	4	8	Signif.[z]
	Butterhead vigor (%)				
PRE[y]	100	85	65	47	L**
PPI	100	100	100	97	NS
Signif.	NS	**	**	**	
	Crisphead vigor (%)				
PRE	100	85	80	33	L**
PPI	100	100	100	100	NS
Signif.	NS	**	**	**	

[z]F tests were significant at the 1% (**) level or nonsignificant (NS) and were linear (L).
[y]Preemergence (PRE) and preplant incorporated (PPI). With no thiobencarb the PRE and PPI values are from the same plot.

increased from 0 to 8 $kg \cdot ha^{-1}$ applied PRE. With the application of thiobencarb PPI, lettuce vigor ratings were not influenced by thiobencarb rate.

Weed control ratings were 10% lower and lettuce vigor ratings were 25% higher with a PPI than PRE application of thiobencarb. Therefore, PPI thiobencarb placement improved the margin of selectivity between lettuce and weeds over that placed PRE.

Irrigation duration and thiobencarb application method study: Zellwood, Spring 1988

The main effects of irrigation duration, thiobencarb rate, and placement method on weed and lettuce data from the spring study are presented in Table 3.52. Weed control, lettuce vigor, and stand were not affected by irrigation duration. Weed control increased from 0 with no thiobencarb, to 30% with 4 $kg \cdot ha^{-1}$ thiobencarb, and was increased only slightly to 38% with 8 $kg \cdot ha^{-1}$ thiobencarb. Lettuce vigor decreased from 100 with no thiobencarb, to 74% with 4 $kg \cdot ha^{-1}$, and decreased more sharply to 30% lettuce vigor with 8 $kg \cdot ha^{-1}$ thiobencarb. Lettuce stand increased from 6.5 to $7.7 \cdot 10^5$ $plants \cdot ha^{-1}$ as thiobencarb rates increased from 0 to 8 $kg \cdot ha^{-1}$. Weed control ratings were not affected by herbicide placement method, but lettuce vigor ratings were higher and stands lower with PPI than PRE placement.

Table 3.52. Main effect of irrigation duration, thiobencarb rate, and placement method on weed control, lettuce vigor, and lettuce stand on an Everglades muck (Spring 1988).

Treatment	Weed control (%)	Lettuce: Vigor (%)	Lettuce: Stand ($10^5 \cdot ha^{-1}$)
Irrigation duration (da at 1.25 $cm \cdot da^{-1}$) (I)			
0	38	81	6.7
4	43	79	6.6
8	41	80	7.4
Signif.[z]	NS	NS	NS
Thiobencarb PRE ($kg \cdot ha^{-1}$) (T)			
0	0	100	6.5
4	30	74	7.2
8	38	30	7.7
Signif.	Q*	Q**	L*
Placement (8 $kg \cdot ha^{-1}$ thiobencarb) (P)			
PRE[y]	38	30	7.7
PPI	36	96	6.4
Signif.	NS	**	**
No herbicide (Ck)			
Unhoed	0	100	6.5
Hoed	100	100	6.8
Signif.	**	NS	NS
Interactions			
I × T	NS	NS	**
I × Ck	NS	NS	**
I × P	NS	NS	**

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).
[y]Preemergence (PRE) and preplant incorporated (PPI).

Lettuce stands were affected by an interaction between irrigation duration and thiobencarb rate, irrigation duration and herbicide placement, and irrigation duration and the herbicide-free treatments (Table 3.53). Lettuce stands were not affected by irrigation duration with 4 $kg \cdot ha^{-1}$ of thiobencarb, but with 0 or 8 $kg \cdot ha^{-1}$ of thiobencarb, lettuce stands were 6.9, 4.7 and 7.8, and 8.4, 6.5, and $8.3 \cdot 10^5 \cdot ha^{-1}$, respectively as irrigation duration increased (0, 4, and 8 days).

Lettuce stands were 2.8 and $2.0 \cdot 10^5 \cdot ha^{-1}$ lower with 0 and 8 days of overhead irrigation, respectively with 8 $kg \cdot ha^{-1}$ of thiobencarb applied PPI than PRE. With 4 days of overhead irrigation, lettuce stands were not affected by application method. In the unhoed (weedy check) treatment, the lowest lettuce stand ($4.7 \cdot 10^5$ $plants \cdot ha^{-1}$) occurred with 4 days of irrigation. Lettuce plant stands with 0 or 8 days of irrigation were not affected by hoeing. Lettuce plant stands with 4 days of irrigation in the hoed check were higher ($7.1 \cdot 10^5$ $plants \cdot ha^{-1}$) than the unhoed check ($4.7 \cdot 10^5$ $plants \cdot ha^{-1}$).

The margin of selectivity increased between weeds and lettuce with thiobencarb applied PPI (no significant difference in weed control and 66% greater lettuce vigor) than PRE as found in the lettuce type tolerance study. The effects of irrigation duration on weed control and lettuce

Table 3.53. Interaction of the irrigation duration and thiobencarb rate, between irrigation duration and unhoed vs hoed checks, and between irrigation duration and placement method on lettuce stand on an Everglades muck (Spring 1988).

	Lettuce stand ($10^5 \cdot ha^{-1}$)			
	Irrigation duration (da at 1.25 $cm \cdot da^{-1}$)			
Treatment	0	4	8	Signif.[z]
Thiobencarb PRE ($kg \cdot ha^{-1}$)				
0	6.9	4.7	7.8	Q**
4	6.1	7.7	7.8	NS
8	8.4	6.5	8.3	Q**
Signif.	Q*	Q**	NS	
Placement (8 $kg \cdot ha^{-1}$ thiobencarb)				
PRE[y]	8.4	6.5	8.3	Q**
PPI	5.6	7.2	6.3	Q*
Signif.	**	NS	*	
No herbicide				
Unhoed	6.9	4.7	7.8	Q**
Hoed	6.4	7.1	6.8	NS
Signif.	NS	**	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were quadratic (Q).
[y]Preemergence (PRE) and preplant incorporated (PPI).

vigor were either nonsignificant, or significant, but did not improve the margin of selectivity between lettuce and weeds. The lack of significant differences due to irrigation duration may also be due to a 3.8 and 3.2 cm rainfall occurrence at 3 and 8 days after planting, respectively.

The soil in the pressed beds were more fluffy after herbicide incorporation (PPI treatments) than with PRE treatments. The fluffy beds (PPI treatments) were difficult to seed with the Planet Jr. planter. Plant stands were lower with the PPI treatments but sufficient plant numbers required (7.0×10^4) to obtain a proper plant stand spacing after blocking were obtained. Problems of inadequate stands can be overcome by increasing the seeding rate or repressing the bed prior to seeding. The greatest degree of weed control (38%) with 8 $kg \cdot ha^{-1}$ thiobencarb applied PRE were not enough to obtain lettuce yields equal to hand cultivated treatments.

Thiobencarb application method and lettuce type tolerance to thiobencarb: Belle Glade, Spring 1988

Data on the effect of thiobencarb rate and placement method on percent control, number and dry weight of weeds are shown in Table 3.54. Weed control increased linearly from 0 to 25% and weed dry weights decreased linearly from

Table 3.54. Main effect of thiobencarb rate and placement method on weed control ratings, weed number and weed weight on a Pahokee muck (Spring 1988).

Treatment	Weed control (%)	Weed growth: Number ($10^5 \cdot ha^{-1}$)	Weed growth: Dry wt ($kg \cdot ha^{-1}$)
Thiobencarb ($kg \cdot ha^{-1}$)			
0	0	4.2	26.8
2	12	4.2	21.9
4	13	4.3	24.3
8	25	3.9	19.6
Signif.[z]	L**	NS	L*
Placement			
PRE[y]	16	4.4	24.7
PPI	17	3.9	21.5
Signif.	NS	*	**
No herbicide			
Unhoed	0	4.2	26.8
Hoed	100	0	0
Signif.	**	**	**

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L).
[y]Preemergence (PRE) and preplant incorporated (PPI). With no thiobencarb, PRE and PPI data are from the same plot.

26.8 to 19.6 kg$\cdot$ha^{-1} as thiobencarb rate increased from 0 to 8 kg$\cdot$ha^{-1}. The number of weeds were not affected by thiobencarb rate. The percent weed control was not affected by herbicide placement; however, weed number and weed dry weight were lower with thiobencarb applied PPI instead of PRE. The number of weeds were $4.2 \cdot 10^5$ weeds$\cdot$ha^{-1} lower and weed dry weights 26.8 kg$\cdot$ha^{-1} lower with hand cultivation.

Data on the effects of thiobencarb rate and placement method on early growth and marketable yield of lettuce are presented in Table 3.55. Butterhead lettuce vigor decreased with the application of thiobencarb from 0 to 2 kg$\cdot$ha^{-1}. However, with 2 to 8 kg$\cdot$ha^{-1} thiobencarb, the butterhead lettuce vigor ratings were similar. Butterhead lettuce stands increased linearly from 8.5 to $11.9 \cdot 10^5$ plants$\cdot$ha^{-1} as thiobencarb rate increased from 0 to 8 kg$\cdot$ha^{-1}. The number and percentage of marketable heads of butterhead lettuce, and crisphead lettuce stand were not affected by thiobencarb rate. With no thiobencarb (unhoed check), only 3.9 MT$\cdot$ha^{-1} of marketable lettuce were harvested. With 2 to 8 kg$\cdot$ha^{-1} of thiobencarb (and hoed at 3 weeks), the butterhead lettuce yields increased from 22.6 to 26.1 MT$\cdot$ha^{-1}. Crisphead lettuce vigor decreased linearly from 100 to 66% with thiobencarb increased from 0

Table 3.55. Main effect of thiobencarb rate and placement method on lettuce vigor, stand, number and percentage of marketable heads, and lettuce yield on a Pahokee muck (Spring 1988).

	Butterhead					Crisphead				
Treatment	Vigor[x]	Stand	Market. heads	Percent market.	Yield	Vigor	Stand	Market. heads	Percent market.	Yield
Thiobencarb ($kg \cdot ha^{-1}$) (T)										
0	100	8.5	7.4	99	3.9	100	15.6	0	0	0
2	75[u]	8.2	7.9	99	22.6[w]	85	10.9	5.9[v]	73[u]	27.7[v]
4	69	9.8	7.6	97	24.5	74	12.6	5.4	65	22.8
8	63	11.9	9.1	96	26.1	66	10.1	6.3	66	31.1
Signif.[z]	C**	L*	NS	NS	Q**	L**	NS	Q**	Q**	Q*
Placement (P)										
PRE[y]	70	8.3	7.9	98	20.4	70	12.9	4.9	57	24.3
PPI	83	10.9	8.0	97	18.2	93	11.7	3.6	44	16.4
Signif.	*	*	NS	NS	NS	**	NS	**	*	**
No herbicide										
Unhoed	100	8.5	7.4	99	3.9	100	15.6	0	0	0
Hoed	100	9.6	7.6	99	26.9	100	15.2	6.9	68	30.8
Signif.	NS	NS	NS	NS	**	NS	NS	**	**	**
Interaction										
T × P	*	NS	NS	NS	NS	*	NS	*	NS	NS

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

[y]Preemergence (PRE) and preplant incorporated (PPI). With no thiobencarb, PRE and PPI data are from the same plot.

Table 3.55--continued.

[x]Vigor (%); Stand ($10^4 \cdot ha^{-1}$); Marketable heads ($10^4 \cdot ha^{-1}$); Percent marketable (%); Yield ($MT \cdot ha^{-1}$).

[w]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was linear.

[v]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was quadratic.

[u]Thiobencarb rate effect for 2, 4 and 8 $kg \cdot ha^{-1}$ was nonsignificant.

to 8 $kg \cdot ha^{-1}$. Weeds in the unhoed plots were about 1 m tall and none of the crisphead lettuce was marketable. With the application of 2 $kg \cdot ha^{-1}$ thiobencarb and hand cultivation at 3 weeks after planting the number of marketable heads, percentage of marketable heads, and crisphead lettuce yield increased to $5.9 \cdot 10^4$ $plants \cdot ha^{-1}$, 73% and 27.7 $MT \cdot ha^{-1}$, respectively. With 4 $kg \cdot ha^{-1}$ thiobencarb, lettuce yield decreased to 22.8 $MT \cdot ha^{-1}$, but increased to 31.1 $MT \cdot ha^{-1}$ with 8 $kg \cdot ha^{-1}$ of thiobencarb.

Butterhead lettuce vigor ratings were 13% higher and crisphead lettuce vigor ratings were 23% higher with thiobencarb applied PPI than as PRE. Butterhead lettuce stands increased from 8.3 to $10.9 \cdot 10^4$ $plants \cdot ha^{-1}$ with thiobencarb applied PPI than as PRE, but crisphead lettuce stands were not affected by thiobencarb placement. The number of marketable heads, percentage marketable, and yield of butterhead lettuce were not affected by thiobencarb placement. The number of marketable crisphead lettuce heads was $1.3 \cdot 10^4$ $plants \cdot ha^{-1}$ lower; percent marketable heads was 13% lower; and yield was 7.9 $MT \cdot ha^{-1}$ lower with thiobencarb applied PPI than as PRE.

Butterhead lettuce vigor, stand, number and percentage of marketable heads, and the crisphead lettuce vigor and stand were not affected by hand cultivation. Butterhead lettuce yield was 23 $MT \cdot ha^{-1}$ higher with hand cultivation. The number of marketable crisphead lettuce

heads was $6.9 \cdot 10^4$ plants$\cdot$ha^{-1} higher, percentage of marketable heads was 68% higher, and yield was 30.8 MT$\cdot$ha^{-1} higher with hand cultivation.

Data on the effects of thiobencarb rate and herbicide placement interacted on butterhead lettuce vigor, crisphead lettuce vigor, and the number of marketable heads of crisphead lettuce are shown in Table 3.56. With 0 or 2 kg$\cdot$ha^{-1} of thiobencarb, butterhead lettuce vigor ratings were not affected by placement method, but with 4 and 8 kg$\cdot$ha^{-1} of thiobencarb, lettuce vigor ratings were 27 and 25% higher, respectively, with thiobencarb applied PPI than as PRE.

Crisphead lettuce vigor ratings were 24, 28, and 37% higher with 2, 4 and 8 kg$\cdot$ha^{-1} of thiobencarb, respectively, applied PPI than as PRE. The number of marketable crisphead lettuce plants were not affected by herbicide placement with 0, 2 or 4 kg$\cdot$ha^{-1} of thiobencarb. With 8 kg$\cdot$ha^{-1} thiobencarb, the number of marketable heads produced with a PRE application ($7.5 \cdot 10^4$ heads$\cdot$ha^{-1}) was greater than with PPI application ($5.0 \cdot 10^4$ heads$\cdot$ha^{-1}) of thiobencarb.

The level of weed control obtained in this study was only 25% with 8 kg$\cdot$ha^{-1} of thiobencarb and was considered very poor. Although statistical differences in weed dry weights were observed, differences were not considered to

Table 3.56. Interaction of thiobencarb rate and placement method on lettuce on an Pahokee muck (Spring 1988).

	Thiobencarb rate ($kg \cdot ha^{-1}$)				
Placement	0	2	4	8	Signif.[z]
	Butterhead lettuce vigor (%)				
PRE[y]	100	75	55	50	Q**
PPI	100	75	82	75	Q*
Signif.	NS	NS	**	**	
	Crisphead lettuce vigor (%)				
PRE	100	73	60	48	L**
PPI	100	97	88	85	L*
Signif.	NS	**	**	**	
	Crisphead lettuce marketable ($10^4 \cdot ha^{-1}$)				
PRE	0	6.5	5.6	7.5	C**
PPI	0	5.2	4.2	5.0	C**
Signif.	NS	NS	NS	**	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L), quadratic (Q), or cubic (C).

[y]Preemergence (PRE) and preplant incorporated (PPI). With no thiobencarb, the PRE and PPI data are from the same plot.

be adequate for lettuce production and additional weed control was needed. Weed competition in the unhoed checks were enough to eliminate lettuce yield. Crisphead lettuce was more sensitive to weed competition than butterhead lettuce because firm head formation is important for crisphead lettuce marketability. In both butterhead and crisphead lettuce, the yields obtained with all rates of thiobencarb applied (and hoed 3 weeks after planting) were similar to the hoed check so any early season weed control obtained was not sufficient to increase yields (i.e. weed competition during the first 3 weeks was inconsequential). Butterhead lettuce yields were not affected by herbicide placement, but crisphead lettuce yields were lower with PPI applications of thiobencarb. A 4-day delay in planting lettuce on soil that was treated with PPI applications of thiobencarb occurred because of 1.65 cm of rain. The delay in planting may have delayed lettuce maturity, decreasing the yield of lettuce with the PPI treatments. In comparing the PRE and PPI treatments, weed numbers and weed weights were lower, lettuce vigor ratings were greater, and stands were equivalent; the 4-day delay in planting may have caused the number and percentage of marketable heads to be significantly lower in the PPI treatments than lettuce from plots that received a PRE application of thiobencarb.

Irrigation duration and thiobencarb application method study: Belle Glade, 1988

Data on the main effect of irrigation, thiobencarb rate, and placement method on weed control in the spring study are presented in Table 3.57. Barnyardgrass, purslane, and the overall (predominantly spiny amaranth [*Amaranthus spinosus* (L.)]) weed control, weed number and weed weight were not affected by irrigation duration. The percent barnyardgrass, purslane, and overall weed control increased from 0 to about 43% with 4 $kg \cdot ha^{-1}$ of thiobencarb, and increased to about 62% with a further increase to 8 $kg \cdot ha^{-1}$ thiobencarb. Weed numbers decreased quadratically (32.6, 29.3, and $25.1 \cdot 10^5$ $weeds \cdot ha^{-1}$) and weed dry weights decreased quadratically (161, 133, and 91 $kg \cdot ha^{-1}$) as thiobencarb rate increased (0, 4, and 8 $kg \cdot ha^{-1}$, respectively). Barnyardgrass, purslane, and overall weed control ratings were 17, 21, and 10% lower, respectively, with 8 $kg \cdot ha^{-1}$ of thiobencarb applied PPI than PRE. Differences in weed control were detected by visual ratings, but actual weed numbers and weed dry weights were not affected by application method.

Weed numbers were affected by interactions between irrigation duration and thiobencarb rate, and between irrigation duration and herbicide placement (Table 3.58). With no thiobencarb, weed numbers increased linearly from

Table 3.57. Main effect of irrigation duration, thiobencarb rate, and placement method on barnyardgrass, purslane, and overall weed control, weed number and weed weight on a Pahokee muck (Spring 1988).

Treatment	Weed control (%)			Weed growth	
	Barnyardgrass	Purslane	Overall[z]	[no·(10^5·ha^{-1})]	Dry wt ($kg·ha^{-1}$)
Irrigation duration (da at 1.25 $cm·da^{-1}$) (I)					
0	53	52	44	20.8	114
4	52	51	46	23.7	92
8	53	56	48	23.9	89
Signif.[y]	NS	NS	NS	NS	NS
Thiobencarb PRE ($kg·ha^{-1}$) (T)					
0	0	0	0	32.6	161
4	46	48	36	29.3	133
8	66	68	52	25.1	91
Signif.	Q**	Q**	Q**	Q**	Q*
Placement (8 $kg·ha^{-1}$ thiobencarb) (P)					
PRE[x]	66	68	52	25.1	91
PPI	49	47	42	26.9	106
Signif.	**	**	*	NS	NS
No herbicide					
Unhoed	0	0	0	32.6	161
Hoed	100	100	100	0	0
Signif.	**	**	**	**	**
Interactions					
I × T	NS	NS	NS	*	NS
I × P	NS	NS	NS	*	NS

Table 3.57--continued.

[z]Overall weed control ratings represent native weeds that were composed of 95% spiny amaranth.
[y]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were quadratic (Q).
[x]Preemergence (PRE) and preplant incorporated (PPI).

Table 3.58. Interaction of irrigation duration and thiobencarb rate, and irrigation duration and herbicide placement on the number of weeds on a Pahokee muck (Spring 1988).

Treatment	Irrigation duration (da at 1.25 $cm \cdot da^{-1}$) 0	4	8	Signif.[z]
	Weed number ($10^5 \cdot ha^{-1}$)			
Thiobencarb PRE ($kg \cdot ha^{-1}$)				
0	27.0	35.4	35.5	L*
4	30.3	25.3	32.2	NS
8	20.7	31.4	23.2	Q**
Signif.	NS	Q*	L**	
Placement (8 $kg \cdot ha^{-1}$ thiobencarb)				
PRE[y]	20.7	31.4	23.2	Q**
PPI	26.1	26.2	28.4	NS
Signif.	NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Preemergence (PRE) and preplant incorporated (PPI).

27.0 to $35.5 \cdot 10^5$ weeds$\cdot$ha^{-1} as irrigation duration increased from 0 to 8 days. Weed numbers were not affected by irrigation duration with 4 kg$\cdot$ha^{-1} of thiobencarb, but with 8 kg$\cdot$ha^{-1} of thiobencarb, weed numbers were greater with 4 days of irrigation ($31.4 \cdot 10^5$ weeds$\cdot$ha^{-1}) than with 0 ($20.7 \cdot 10^5$ weeds$\cdot$ha^{-1}) or 8 days ($23.2 \cdot 10^5$ weeds$\cdot$ha^{-1}). The 8 days of overhead irrigation did not actually improve the activity of thiobencarb (as implied by the linear decrease in weed number with increasing thiobencarb rate), but it increased the number of weeds in comparison to no overhead irrigation when no herbicide was applied, allowing significant decreases in weed number to be detected as thiobencarb rate increased. The germination and growth of purslane (Yamamoto and Ohba, 1977) and horse purslane (Janiya and Moody, 1984) were favored by overhead irrigation, so increases in herbicidal activity by increasing soil moisture may also result in greater weed growth.

The greatest number of weeds ($31.4 \cdot 10^5$ weeds$\cdot$ha^{-1}) occurred with 8 kg$\cdot$ha^{-1} of thiobencarb applied PRE with 4 days of irrigation, but weed numbers were not affected by irrigation duration with thiobencarb was applied PPI.

Data on the main effect of irrigation, thiobencarb rate, and placement method on lettuce vigor, stand, number and percentage of marketable heads, and yield data are shown in Table 3.59. All parameters of lettuce growth were

Table 3.59. Main effect of irrigation duration, thiobencarb rate, and placement method on lettuce vigor, stand, number of marketable heads, percentage of marketable heads and yield on a Pahokee muck (Spring 1988).

Treatment	Vigor (%)	Stand ($10^4 \cdot ha^{-1}$)	Marketable heads ($10^4 \cdot ha^{-1}$)	Percent marketable (%)	Yield ($MT \cdot ha^{-1}$)
Irrigation duration (da at 1.25 $cm \cdot da^{-1}$) (I)					
0	84	17.7	4.3	57	51
4	85	20.9	4.1	54	50
8	83	22.6	4.8	60	55
Signif.[z]	NS	NS	NS	NS	NS
Thiobencarb PRE ($kg \cdot ha^{-1}$) (T)					
0	100	21	0	0	0
4	71	14	5.6	74	69
8	59	17	5.4	70	62
Signif.	L**	NS	Q**	Q**	Q**
Placement (8 $kg \cdot ha^{-1}$) thiobencarb					
PRE[y]	59	17	5.4	70	62
PPI	90	28	5.7	73	66
Signif.	**	*	NS	NS	NS
No herbicide (Ck)					
Unhoed	100	21	0	0	0
Hoed	100	20	5.4	69	63
Signif.	NS	NS	**	**	**
Interactions					
I × T	NS	**	NS	NS	NS
I × Ck	NS	*	NS	NS	NS

Table 3.59--continued.

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Preemergence (PRE) and preplant incorporated (PPI).

not influenced by irrigation duration. Lettuce vigor decreased linearly from 100 to 59%, but lettuce stand was not affected with an increase in thiobencarb rate from 0 to 8 kg$\cdot$ha^{-1}. The number of marketable lettuce heads, percent marketable and lettuce yields increased sharply from no lettuce obtained with no thiobencarb (unhoed check) to similarly greater lettuce yields with 4 or 8 kg$\cdot$ha^{-1} (which were also hand hoed at 3 weeks) of thiobencarb. Lettuce vigor and stand were 31% and 11$\cdot$10^{4} plants$\cdot$ha^{-1} higher, respectively, with 8 kg$\cdot$ha^{-1} of thiobencarb applied PPI than as PRE. The number of marketable lettuce heads, percent marketable, and lettuce yield were not affected by herbicide placement. With no cultivation, there were no marketable lettuce heads, but with cultivation there were 5.4$\cdot$10^{4}$\cdot$ha^{-1} marketable heads, 69% of the total number of lettuce heads were marketable and the lettuce yield was 63 MT$\cdot$ha^{-1}.

Lettuce stands were affected by interactions between irrigation duration and thiobencarb rate, and between irrigation duration and unhoed versus hoed plots (Table 3.60). Lettuce stand increased linearly from 10.8 to 31.7$\cdot$10^{4} plants$\cdot$ha^{-1} with an increase in irrigation duration from 0 to 8 days with no thiobencarb. However, lettuce stands were not affected by irrigation duration

Table 3.60. Interaction of irrigation duration and thiobencarb rate, and irrigation duration and unhoed vs hoed checks on lettuce stand on a Pahokee muck (Spring 1988).

Treatment	Irrigation duration (da at 1.25 cm·da^{-1}) 0	4	8	Signif.[z]
	Lettuce stand (10^4·ha^{-1})			
Thiobencarb PRE (kg·ha^{-1})				
0	10.8	26.9	31.7	L**
4	19.7	11.4	10.8	NS
8	10.2	23.9	17.9	NS
Signif.	NS	Q*	Q*	
No herbicide				
Unhoed	10.8	26.9	31.7	L**
Hoed	21.5	19.1	19.7	NS
Signif.	NS	NS	NS	

[z]F tests were significant at the 5% (*) or 1% (**) level, or nonsignificant (NS) and were linear (L) or quadratic (Q).

[y]Preemergence (PRE) and preplant incorporated (PPI).

with 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb. Lettuce stands increased linearly from 10.8 to $31.7 \cdot 10^4$ lettuce $plants \cdot ha^{-1}$ as irrigation duration increased from 0 to 8 days with the unhoed treatment, but lettuce stands were not affected by irrigation duration with the hoed treatment.

Lettuce yields were greater with 4 or 8 $kg \cdot ha^{-1}$ of thiobencarb (which were also hand hoed) than with no thiobencarb (an unhoed check), but were similar to the hoed check. The similar yields in these treatments indicate that hoeing, not thiobencarb rate, was important for the greater yields with hand cultivation. Thiobencarb applied at 4 or 8 $kg \cdot ha^{-1}$ reduced the number and weight of weeds, and thereby reduced the labor needed for hoeing. Averaging over all experiments, weed number was reduced by $5.3 \cdot 10^5$ $weeds \cdot ha^{-1}$ and weed weight was reduced by 237 $kg \cdot ha^{-1}$ by applying 8 $kg \cdot ha^{-1}$ of thiobencarb. In the Zellwood fall study, PRE applications of 8 $kg \cdot ha^{-1}$ of thiobencarb were phytotoxic to lettuce and resulted in a yield reduction. In the spring study, injury to lettuce from thiobencarb was observed at 3 weeks after planting, but lettuce yields were not affected by the early season injury.

The higher temperatures at planting in the fall would tend to make thiobencarb more active (Rich, 1981) due to more thiobencarb in the solution (desorbed phase) (McGlamery and Slife, 1966). Greater amounts of thiobencarb may have been available for lettuce uptake.

Warmer temperatures could also increase root growth, thereby increasing thiobencarb uptake via interception and mass flow (Lavy, 1968). Reiners et al. (1988) attributed the greater uptake and susceptibility of 'Dark Green Boston' lettuce than 'Great Lakes 366' to a 50% longer root system in the 'Dark Green Boston' lettuce. Decreasing temperatures as the season progressed in the fall may have slowed the recovery of lettuce from thiobencarb injury. Thiobencarb has also been shown to have greater residual activity at lower temperatures (Rich, 1981).

The 4 $kg \cdot ha^{-1}$ of thiobencarb PRE or 8 $kg \cdot ha^{-1}$ PPI resulted in similar lettuce yields at Zellwood (on an Everglades muck soil) and also provided some weed suppression. These treatments along with hand hoeing at 3 weeks appears adequate for season long control because temperature reductions during the growing season were enough to inhibit weed competition. In Belle Glade, the highest rate of thiobencarb evaluated (8 $kg \cdot ha^{-1}$) did not provide enough weed suppression to increase yields over the unhoed (weedy) check.

Irrigation duration effects were generally nonsignificant. The percent lettuce vigor ratings with thiobencarb applied PPI were higher than with PRE applications, and weed control ratings were similar with thiobencarb applied PPI or PRE, but placement generally had no effect on yield in the spring.

It is apparent from these studies that thiobencarb did not provide season long control of weeds for lettuce grown on muck soil. Application of low rates of thiobencarb in combination with other herbicides should be evaluated to provide more effective weed control without serious loss of lettuce vigor.

CHAPTER IV
SUMMARY

Laboratory studies were conducted to determine the relationship between soil physical and chemical characteristics and thiobencarb behavior. The effect of management practices on the weed control efficacy of thiobencarb were evaluated in greenhouse and field studies.

Thiobencarb adsorption on soil was in the order Pahokee muck > Everglades muck > Immokalee sand with K_f values of 339, 169 and 14 $ml \cdot g^{-1}$, respectively. The adsorption values were correlated with the soil organic carbon content of these soils ($r = 0.97$). The adsorption values per unit of organic carbon (K_{oc}) were in the order Immokalee sand > Pahokee muck > Everglades muck with K_{oc} values of 1195, 765, and 539 $ml \cdot g^{-1}$, respectively. Thiobencarb desorption values were inversely proportional to the adsorption values with < 5% of thiobencarb removal per desorption with 8 ml of 0.01 N $CaCl_2$ from the muck soils. On all three soils > 93% of thiobencarb applied remained in the top 1.0 cm of the soil column after the column was leached during unsaturated flow with 0.01 N $CaCl_2$ to a depth of 20 cm. The retardation factor

(R_T) for thiobencarb during saturated flow (3 $ml \cdot min^{-1}$ of 0.01 $CaCl_2$) on the Immokalee sand was 67.9, 20.0, 1.94, and 1.16 with 0, 25, 50, and 75% by volume methanol in 0.01 N $CaCl_2$, respectively. A significant log-linear relationship ($r = 0.98$) occurred between the adsorption values (K_f) estimated from R_T values and the percentage by volume methanol of the leachate. The adsorption value estimated from the saturated flow study without methanol was similar to that found in the adsorption experiment. The half-life of thiobencarb on the three soils averaged 19.6 days and ranged from 12.3 to 32.6 days, depending on soil series, temperature, and soil-water tension. The half-life of thiobencarb generally was shorter with an incubation temperature of 35° than 25°C and a soil-water tension of 10 than 100 kPa. During the degradation process, the extractable ^{14}C, bound ^{14}C, and $^{14}CO_2$ recovered from ^{14}C-thiobencarb treated soil was affected by an interaction between time of incubation, soil series, temperature, and soil-water tension. The percentage extractable ^{14}C recovered was in the order Immokalee sand > Everglades muck > Pahokee muck. The percent of bound ^{14}C recovered by soil combustion was inversely proportional to percent extractable ^{14}C recovered. This is in agreement with adsorption studies that indicated greater adsorption on the

muck soils than on the sand. The percent of ^{14}C recovered as $^{14}CO_2$ accounted for less than 1% of the ^{14}C recovered at any day or treatment combination. Generally the percent extractable ^{14}C was greater at 25°C than at 35°C.

Greenhouse and field studies on the effects of soil series, irrigation duration and method, and thiobencarb application method on lettuce vigor and weed control were conducted. In greenhouse studies, reductions in lettuce or weed plant stands due to thiobencarb occurred between 7 and 14 days after planting and were reduced more on the Immokalee sand than the muck soils. The overall greater activity of thiobencarb on the Immokalee sand is in agreement with its lower adsorption values. Butterhead and crisphead lettuce plant stands were lower at 100 kPa than 10 kPa soil-water tension with 4 $kg \cdot ha^{-1}$ thiobencarb, but were equally lower with 8 $kg \cdot ha^{-1}$. Barnyardgrass, purslane and bermudagrass plant stands were not affected by soil-water tension, but the percent bermudagrass control was greater with 100 than 10 kPa soil-water tension. Overall, the soil-water tension had a greater effect on lettuce vigor or weed control on the Immokalee sand than the muck soils. Lettuce dry weight was not affected by thiobencarb rate on the muck soils but decreased on the Immokalee sand as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$.

Activated charcoal applied on top of crisphead lettuce seed within the furrow at 1.4 $g \cdot ml^{-1}$ enabled lettuce to attain a similar dry weight with 0 or 8 $kg \cdot ha^{-1}$ of thiobencarb, while naphthalic anhydride did not provide protection for lettuce.

In general, overhead irrigation in combination with thiobencarb reduced lettuce stand, vigor, and dry weight on the Immokalee sand more than with subsurface irrigation. The overhead irrigation may have desorbed greater amounts of thiobencarb from the Immokalee sand than the muck soils, leaching it into the seed zone, while subsurface irrigation concentrated it close to the soil surface. Lettuce vigor, weed control, and dry weight decreased linearly on the muck soils and quadratically on the sand as thiobencarb rate increased from 0 to 8 $kg \cdot ha^{-1}$.

Lettuce stand was greater with a preplant incorporated than preemergence application of 8 $kg \cdot ha^{-1}$ thiobencarb on all soils. Barnyardgrass and purslane stand were reduced more with a preemergence thiobencarb application on the muck soils but were equally lower on the sand. Lettuce vigor ratings were high while barnyardgrass and purslane control ratings were slightly lower with a preplant incorporated than a preemergence application of 8 $kg \cdot ha^{-1}$ thiobencarb on the muck soils, but both application methods were similarly phytotoxic on the sand. Lettuce dry weights

were higher with 8 kg·ha^{-1} thiobencarb applied PPI than as PRE with subsurface irrigation. Lettuce dry weights decreased and were not affected by thiobencarb application method with overhead irrigation.

In field studies butterhead and crisphead lettuce yields were higher with the PPI than PRE application of 8 kg·ha^{-1} thiobencarb in the fall but were similar in the spring study. Lettuce vigor ratings were higher with the preplant incorporated than preemergence application of 4 or 8 kg·ha^{-1} thiobencarb with 4 or 8 days of overhead irrigation, but were not affected by thiobencarb application method with no overhead irrigation in the fall. Overhead irrigation duration did not affect weed control or lettuce yield.

In conclusion, the adsorption of thiobencarb on the soils studied prevented extensive leaching, therefore the potential for groundwater contamination is minimal. The general lack of an effect of overhead irrigation duration on thiobencarb activity in the field was in agreement with the low amounts of desorbable thiobencarb found in the laboratory studies. The preplant incorporated treatments tended to increase the margin of selectivity between lettuce and weeds, and appeared to be a beneficial practice in the fall but not spring. Overall, thiobencarb provided moderate to poor early season weed control but reduced hoeing costs due to smaller weed sizes and numbers;

however, thiobencarb applications without hand hoeing resulted in lettuce yields similar to those with the unhoed checks.

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I certify that I have read this study and in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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